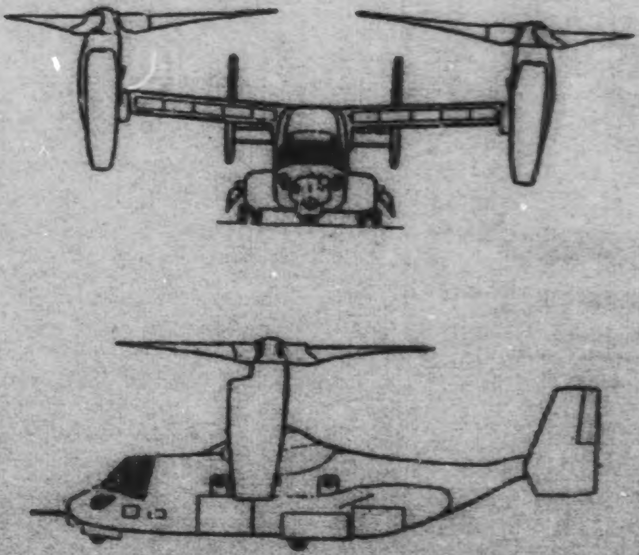

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TILTROTOR/VERTIPORT PLANNING AND DEVELOPMENT IN CANADA

TECHNICAL REPORT

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June 1992

by:

APA Airport Planning Associates Inc.

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16. Abstract

This report draws a general portrait of CTR technology and its possible applications in the Canadian context. It includes a review of the evolution and current status of tiltrotor technology, a description of the vehicle and its operational characteristics, a complete and coordinated presentation of the criteria and parameters necessary for the planning of facilities and procedures to accommodate CTR services in Canada and an analysis of Canadian market potential for CTR services. It does not devote any particular attention to those aspects which relate to airline operations and economics, nor does it consider the issues of civil certification of CTR aircraft and pilots.

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16. Résumé

Le présent rapport dresse un tableau général de la technologie des appareils convertibles à rotors basculants et de ses applications possibles au Canada. Il fait le survol de l'évolution et de l'état actuel de la technologie des rotors basculants, la description de l'appareil et de ses caractéristiques opérationnelles, un inventaire exhaustif et cohérent des critères et des paramètres à prendre en compte dans la planification des installations et des procédures devant mener à l'implantation de services de transport par avion convertible à rotors basculants au Canada, ainsi qu'une analyse du marché potentiel de ces services au Canada. Le rapport ne traite pas spécifiquement de l'exploitation commerciale de ces avions ni des coûts d'une telle exploitation, et passe sous silence les questions relatives à la certification des appareils et à la délivrance des licences de pilotes.

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PREFACE

Background

Tiltrotor technology offers some of the most innovative and potentially valuable advances in aviation since the advent of the jet engine. These aircraft represent a "third stream" in the development of air transportation, alongside fixed-wing and helicopter craft. With their proprotor assemblies capable of tilting from a vertical to a horizontal alignment vis-à-vis the fuselage, tiltrotor aircraft constitute in many respects a hybrid of these two. This feature enables tiltrotors to combine the manoeuverability of helicopters with the cruising speed of fixed-wing aircraft (300 mph). When in horizontal position, the proprotors mounted at its wing tips permit the aircraft to lift off, hover and land like a helicopter; when the blades tilt forward, the aircraft accelerates and cruises at high speed.

The new technology is seen as a significant aid to solving the ground access and airside congestion problems currently plaguing the air transportation system. The aircraft does not require large airports with long runways; instead, specialized vertiports occupying a fraction of the space will permit the aircraft to provide direct air service in places where this is not now feasible: city centers, remote sites, rugged terrain, etc. Tiltrotor services may operate at conventional airports, but they are also expected to give rise to entirely new facilities, called vertiports, which may be developed on as little as 4 acres of land.

The technical feasibility of tiltrotor technology was first demonstrated in 1958 when Bell Helicopter produced the XV-3. In 1979, the XV-15 tiltrotor test vehicle developed by Bell in response to U.S. Army requirements commenced an intensive long-term evaluation programme. More recently, a joint team of Bell Helicopter Textron and Boeing Helicopter has undertaken a major programme to develop a multi-mission tiltrotor aircraft for the U.S. Department of Defense and has successfully produced and flown prototypes of this vehicle, the V-22 Osprey.

Civil derivatives of this aircraft, as well as other tiltrotor craft, have been proposed for a number of roles which would expand and enhance civil aviation throughout the world, by taking advantage of the unique flying capabilities of the vehicle. The U.S. Congress, in response to the findings of studies by the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA), the Department of Defense (DOD), the Port Authority of New York and New Jersey (PANYNJ), Bell Helicopter Textron and Boeing Aircraft, has mandated the FAA to coordinate a special nation-wide programme to advance the development of civil tiltrotor. As part of this mandate, FAA has publicly invited other countries to participate in the effort to aggressively develop and implement a civil tiltrotor (CTR) air transportation system in order to (1) alleviate conventional airport and airways congestion, (2) provide improved downtown-to-downtown transportation and (3) make air services to difficult sites more feasible.

The present study explores planning criteria and parameters for the development of civil tiltrotor/vertiport air services and examines the applications and feasibility of civil tiltrotor in Canada. It complements a number of studies conducted in the United States. It is expected that this study will assist in decisions concerning the selection, development and analysis of sites which could eventually be suitable for Canadian tiltrotor air service in conjunction with an eventual FAA demonstration programme.

Objectives and Scope of the Study

The principal objectives of the present study are:

1) to provide decision-makers with a concise, complete and coordinated description of tiltrotor air transportation: historical progress, current status and expected future development; characteristics of the CTR vehicle; type of service to be provided; special infrastructure requirements; potential for enhancement of the overall air transportation system in Canada.

2) to explore planning criteria and parameters for the development of civil tiltrotor/vertiport air services applicable to the Canadian context.

3) to assess the market potential of the application of this technology as a means of providing regular scheduled air service in Canada.

Scope and Organisation of Report

The present report draws a general portrait of CTR technology and its possible applications in the Canadian context, including a review of the evolution and current status of tiltrotor technology, a description of the vehicle and its operational characteristics, a complete and coordinated presentation of the criteria and parameters necessary for the planning of facilities and procedures to accommodate CTR services in Canada and an analysis of Canadian market potential for CTR services. It does not devote any particular attention to those aspects which relate to airline operations and economics, nor does it consider the issues of civil certification of CTR aircraft and pilots. The report is organized according to the following chapter headings:

Chapter 1, **Development Overview** provides an overview of the historical and current development of tiltrotor technology.

Chapter 2, **CTR Vehicle Description** provides a concise description of the performance characteristics, applications and likely general configurations of the CTR vehicle.

Chapter 3, **Operational Parameters**, discusses CTR operations in terms of critical parameters relevant to the planning and development of the required infrastructure, including characteristics of CTR air services, CTR vehicle parameters, ATC and flight procedures.

Chapter 4, **Air Navigation System**, discusses the components of the aeronautical infrastructure and the accommodation of CTR operations in the Canadian air navigation system.

Chapter 5, **Vertiports**, discusses the criteria relative to the planning and development of specialized vertiport facilities to accommodate CTR operations.

Chapter 6, **Environmental Considerations**, discusses the impacts of CTR operations on the environment.

Chapter 7, **Potential Application of Civil Tiltrotor in Canada** identifies the major Canadian city-centre and other markets which would significantly benefit from introduction of CTR service, including an estimation of traffic flows associated with CTR operations.

In addition to the above-mentioned chapters, a series of technical appendices provide additional details on the following specific subjects:

Appendix 1 presents technical data on the only significant Canadian contribution to the development of tiltrotor technology to date: the Canadair CL-84.

Appendix 2 provides technical specifications on the various CTR aircraft under development or in the planning stage as of this writing.

Appendix 3 discusses the issues concerning the trade-offs involved in enhanced CTR vehicle and system capabilities versus reduced airspace requirements.

Appendix 4 presents the bibliography of published works consulted in the course of the current study.

Appendix 5 presents a similar bibliography of unpublished works.

Appendix 6 provides a descriptive list of CTR / vertiport planning studies which have been undertaken by various planning and aviation agencies.

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1. DEVELOPMENT OVERVIEW

The present chapter provides background on the historical evolution and current on-going development of tiltrotor technology and its implementation as part of the air transportation mode.

1.1 Historical Perspective

The historical evolution of tiltrotor technology can be summarized in four major phases, going back to the pre-World War II period. During this 50-year time span the development of tiltrotor technology took place in parallel with other advances in both fixed wing and helicopter aeronautics, as can be seen in Table 1, which shows the first tiltrotor project to be contemporary with Sikorsky's first helicopter flight and the development of the first real airliners.

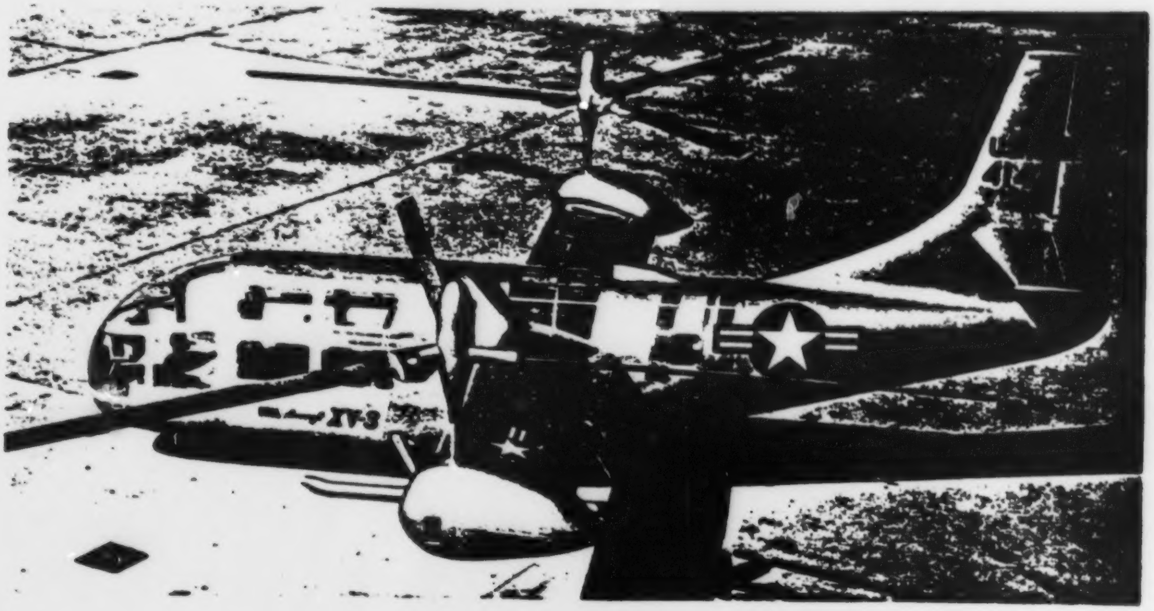
First Phase

The first phase of tiltrotor development can be considered as preliminary and consisted of conceptual development projects, research and scale models. In the late 1930s, while Igor Sikorsky successfully took off vertically in the world's first helicopter, a British patent was issued for the first tiltrotor aircraft: the Baynes Heliplane.At that time, however, the aviation industry had other priorities and the British project was not pursued further.

Second Phase

During World War II, German aviation initiated work on the development of a convertiplane fighter, the Focke-Achgelis FA 269, but the results of this effort were lost in the wartime destruction. After the war, the production of the U.S. McDonnell XV-1 and the Sikorsky stoppable-rotor XV-2 helicopter contributed directly to the development of tiltrotor technology. The first concrete demonstration of the feasibility of the basic tiltrotor concept was achieved with the Bell Helicopter XV-3 aircraft programme. Designed and built by Bell, the XV-3 tiltrotor aircraft (shown in Figure 1) made its first full conversion from helicopter to fixed-wing flight modes in December 1958. Ground and air tests, as well as wind tunnel analyses, were made on the XV-3 over the course of the following seven years.

FIGURE 1
BELL XV-3 TILTROTOR AIRCRAFT



Third Phase

During the 1960s, several research and development programmes related to tiltrotor technology were undertaken by the aviation industry, some of which could not be fully implemented due to financial constraints. These experiments did, however, contribute much invaluable knowledge to the development of the technology. The Canadian Canadair CL-84 (Figure 2 and Appendix 1) and the U.S. LTV XC-142 are two examples of a tilting wing variant of the basic concept.

During this period, however, the successful testing of the Bell XV-3 ultimately led to the launching of the XV-15 tiltrotor research aircraft programme in the early 1970s. The U.S. Army and NASA awarded a contract to Bell Helicopter to develop two XV-15 tiltrotor technology demonstrator aircraft (Figure 3). The first of these craft made its maiden flight in 1977. The validity of the tiltrotor concept was confirmed and proof was obtained that the technical issues had been identified and fully understood.

FIGURE 2
CANADAIR CL-84 TILT WING AIRCRAFT

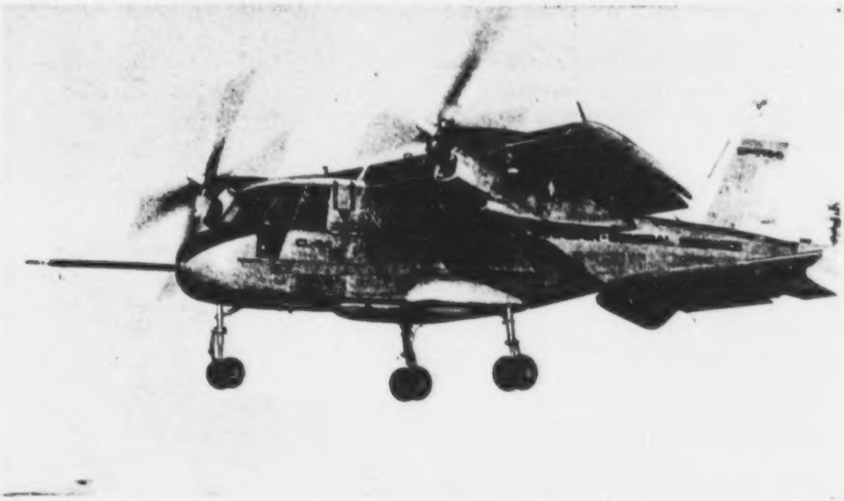
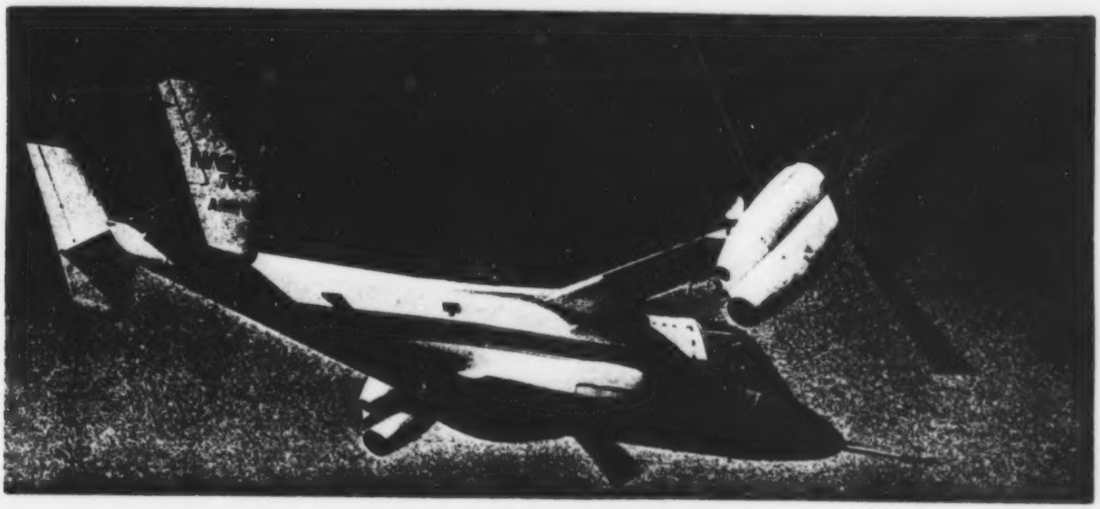


FIGURE 3
BELL XV-15 TILTROTOR AIRCRAFT



Fourth Phase

Based on the success of the XV-15 programme, the military application of the technology proceeded with the decision on the part of the US Congress and Department of Defence (DOD) to begin full-scale development of the V-22 Osprey aircraft, illustrated in Figure 4. Initiated in 1983, this is a major technological development and production programme, rather than a research exercise, and is intended to lead to the fabrication of some 600 military aircraft for the U.S. armed forces, with variety of missions. The prime contractor is a consortium of Bell Helicopter Textron and Boeing Vertol, referred to as Bell/Boeing. The first V-22 prototype made its maiden flight on March 19 of 1989, and the second in August of the same year.

FIGURE 4
BELL/BOEING V-22 OSPREY TILTROTOR AIRCRAFT

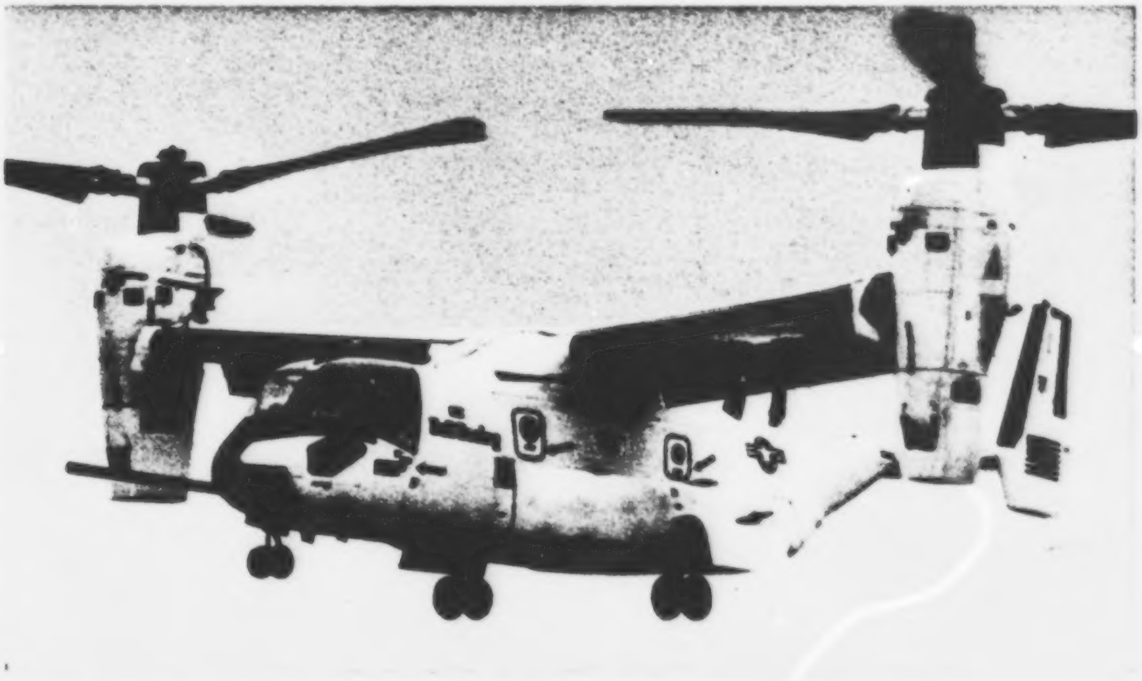


TABLE 1
COMPARATIVE CALENDAR OF THE EVOLUTION OF AVIATION TECHNOLOGY

YEAR	TECHNOLOGY	EVENT
1903	FW	1st powered flight (Wright brothers)
1909	FW	1st English Channel crossing (Blériot)
1920	FW	1st Trans-Canada flight
1931	FW	1st Trans-Altantic crossing (Lindberg)
1936	FW	1st modern airliners (DC3, etc.)
1939	HE	1st helicopter flight (Sikorsky)
1935-40	**TR**	**1st tiltrotor design (Baynes Heliplane)**
1945-49	FW	1st pressurized airliners (DC6, Constellation, etc.)
1958	**TR**	**1st tiltrotor conversion flight (XV-3)**
1955-60	FW	1st jet airliners (B707, DC8, Caravelle, etc.)
1970	FW	1st wide-body airliners (B747, DC10, L1011, etc.)
1975	FW	1st supersonic airliner (Concorde)
1979	**TR**	**XV-15 makes 1st successful conversion flight**
1989	**TR**	**V-22 makes 1st successful conversion flight**

FW: Fixed-wing

HE: Helicopter

TR: Tiltrotor

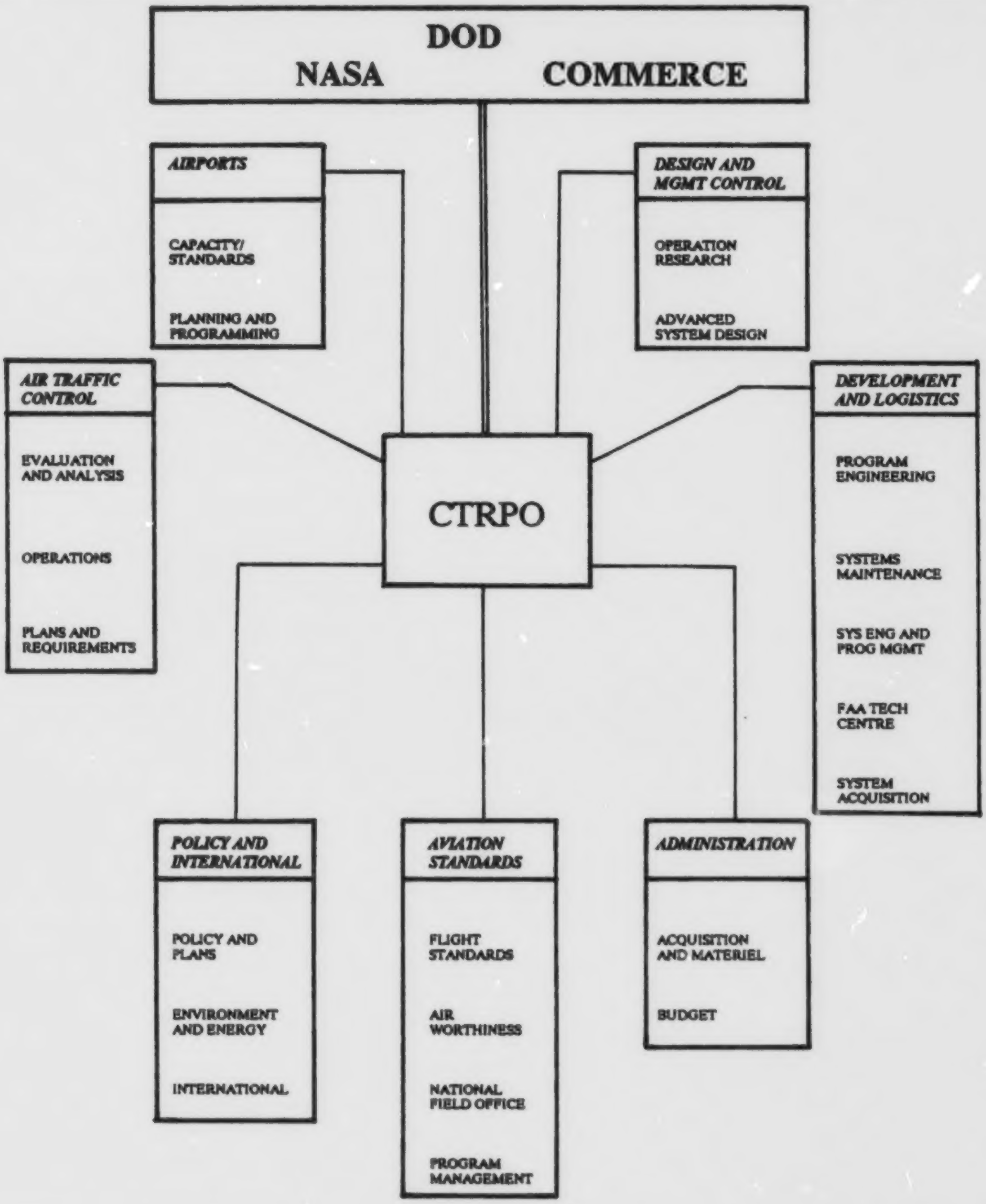
1.2 Current Status

Within the US, continuing research and development of the military V-22 tiltrotor programme led to recognition of the value of this technology for civil and commercial application and the specific benefits of this technology in enhancing the safety and capacity of the US national airspace system. In order to encourage the development of civil derivatives of the tiltrotor concept for inter-city and regional trans-portation, the Federal Aviation Administration (FAA), National Aeronautics and Space Administration (NASA) and DOD have jointly funded a number of studies since 1985 addressing the following issues: (1) the technical, economic and market assessment of a civil variant of the V-22; (2) the potential for other variants and sizes of civil tiltrotor aircraft; (3) civil certification of aircraft procedures, infrastructure and personnel; (4) indirect technology spin-offs; (5) the impact of civil production on the defense industrial base. These studies were executed with the active participation of manufacturers such as the Boeing Commercial Airplane Company, Bell Helicopter Textron and Boeing Vertol, and with support from the US Department of Transportation (DOT). The conclusions of these studies indicated that the new technology could play a potentially significant role in enhancing air transportation in the US, in terms of increased capacity, safety and service to the public.

In August of 1988, the FAA announced a five point programme that would speed the introduction of tiltrotor technology into the national air transportation system. The establishment of a Civil Tiltrotor Program Office (CTRPO) within the FAA forms a critical part of this programme. The office is mandated to coordinate all activities within the FAA and with other agencies such as DOD, Department of Commerce (DOC), NASA, local, state and other federal agencies. Accordingly, the CTRPO prepared in December 1988 a National Civil Tiltrotor Implementation Plan (NCTRIP), which defines the responsibilities of the organizations involved and provides guidance to the FAA and other government agencies in its implementation. The Figure 6 shows the general coordination functions and relationships of the CTRPO.

In 1987, cognizant of the increasingly severe problems of "multimodal gridlock" in the New York metropolitan area (comprising parts of the states of New York, New Jersey and Connecticut), the Port Authority of New York and New Jersey (PANYNJ) undertook a feasibility study of the potential for improvement of short-haul door-to-door passenger service via the introduction of center-to-center tiltrotor air services which would alleviate airport and ground congestion. The results led to further studies of site selection for possible vertiports in the metropolitan area and the feasibility of tiltrotor use at the three airports of the New York area. A number of foreign organizations have also demonstrated their interest in the technology by undertaking their own programmes: (1) EUROFAR (European Future Advanced Rotorcraft), a manufacturing consortium involving the participation of companies from France, Germany, Italy, Spain and the U.K., and (2) Ishida Corporation, a Japanese-financed development group operating in the US.

FIGURE 5
CIVIL TILTROTOR SPECIAL PROJECT OFFICE



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BUDGET

1.3 Active Development and Application Programmes

Based on these past efforts a number of tiltrotor development and application programmes are currently being actively pursued by airport authorities, civil aviation agencies, aircraft manufacturers and research organizations on an increasingly global basis. This section of the report is intended to provide an overview of these programmes in terms of their objectives, scope, timing and level of resources involved. For the purposes of the present exercise, the current programmes can be divided into three general areas: (1) tiltrotor vehicle development; (2) vertiport siting requirements and planning studies; (3) CTR infrastructure and air system requirements to support tiltrotor operations. The information summarized in Table 2 was obtained on the basis of questionnaires and interviews involving the key organizations and individuals working in this field, including:

FAA (CTRPO and other departments)
NASA
Bell Helicopter Textron
Boeing Vertol
Port Authority of New York and New Jersey
State and local airport and aviation authorities
American Helicopter Society
E.H. Industries

1.3.1 Vehicle Development Programmes

Bell-Boeing

The V-22 Osprey programme, initiated in 1981 by the United States Joint Armed Services, is essentially intended for military missions. The US Army, Navy, Marine Corps and Air Force would each have their own special applications for the V-22. The programme schedule consists of three main stages: (1) the preliminary design stage, which was completed in mid-1986; (2) the full-scale development stage, to be completed by early 1992; (3) the production stage, during which the first delivery to the Marine Corps is expected in 1993, depending on US military budget allocations. As of January 1990, this programme has resulted in the construction of three aircraft as part of the development stage. A fourth is scheduled for delivery in the Spring of 1990 and at the end of this stage (by 1993), a total of 6 aircraft will have been delivered. A total of 657 aircraft are scheduled for production: 552 for the Marines, 50 for the Navy and 55 for the Air Force. According to recent news reports, cutbacks in US military equipment allocations may result in delays and reductions in the proposed delivery schedules.

TABLE 2
CURRENT CTR DEVELOPMENT PROGRAMMES

Vehicle Development Programmes

Bell-Boeing: V-22 Osprey programme
NASA: Rotorcraft Research and Technology Development Program
FAA: National Civil Tiltrotor Initiative Program
EUROFAR: Tiltrotor commercial air transport aircraft
Ishida Corporation: Tilting wing T-68 aircraft
MAGNUM T/R: Civil adaptation of Bell XV-15 test aircraft
E.H. Industries: EH-101 helicopter
McDonnell Douglas Helicopter Company: MD-900 advanced helicopter design
Sikorsky Helicopter: Civil transport helicopter design
USSR: Tilt-wing aircraft development

Vertiport Siting Requirements and Planning Studies

PANYNJ: Feasibility of tiltrotor use at the three airports of the New York area
PANYNJ: Site study for tiltrotor vertiport in Manhattan
Washington D.C.: Vertiport/helistop feasibility study
State of California: State-wide civil tiltrotor aircraft feasibility study
Southern California Association of Governments (SCAG)
San Francisco
State of Texas: Vertiport design study
Dade County (Florida)
Puerto-Rico/Caribbean Region
State of Illinois
State of Alaska
St. Louis
Orlando
State of South Dakota
Boston
Montreal

CTR Infrastructure and Air System Requirement Programmes

AHS/FAA (Vertiport Working Group): Vertiport Design Advisory Circular AC150/53xx-xx
FAA: National Civil Tiltrotor Implementation Plan

NASA

NASA is conducting a number of related rotorcraft research and technology development programmes, including civil tiltrotor R&D efforts. A report which would provide a framework for technical support activities, including general rotorcraft R&D needs and opportunities over a 5 to 10 years period, is planned for July 1990.

FAA

As part of the five-point programme mentioned earlier in this report, the FAA has established a set of specific goals to be achieved with respect to the certification of CTR for use in the US air transportation system. Provisional certification of an unpressurized 30 - passenger civil version of the V-22 for the purposes of feasibility demonstrations, is scheduled for December 1992. Full certification of a pressurized civil V-22C is set for late 1995. According to the FAA, when similarity is found between the specifics of powered lift and fixed wing concepts, established airplane and rotorcraft standards could serve as criteria for the certification of the design. Otherwise, new criteria would be required.

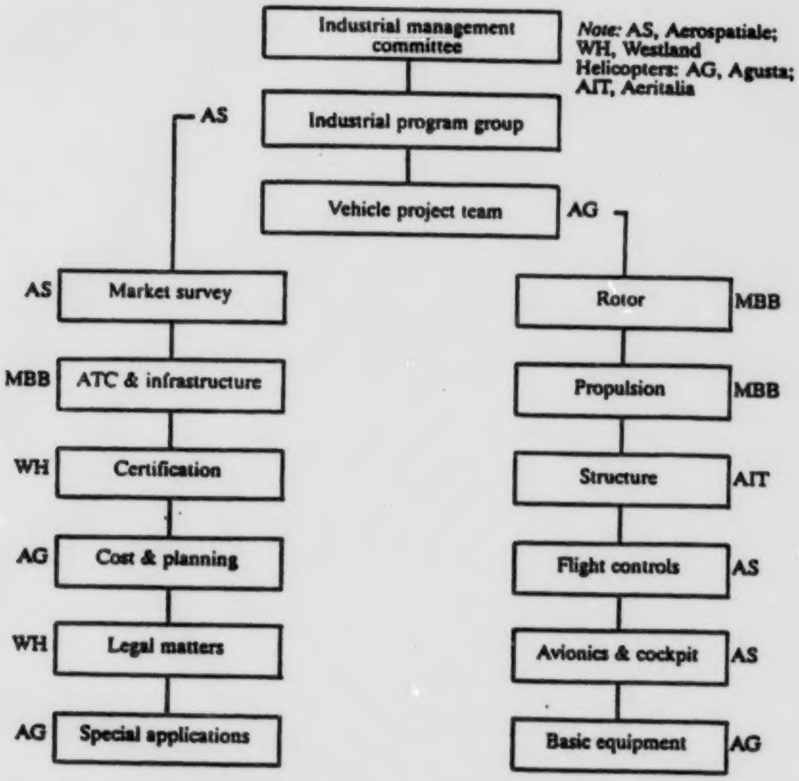
EUROFAR

The European Future Advanced Rotorcraft is a 3-phase aircraft development programme which involves the participation of five companies from different European countries (France, Germany, Italy, Spain and the United Kingdom). The programme commenced in 1987 under the auspices of the European Research and Coordination Agency (EUREKA), whose members include all the countries of the EEC. The first phase, lasting three years, was completed in 1990. Its principal objectives were three-fold:

1) evaluation of the market potential for a tiltrotor vehicle by the end of the century;
2) determination of the specific European interest in this field;
3) execution of studies needed to gather elements for a decision about future European tiltrotor activities.

As shown in Figure 6, this is seen as a broad programme, involving not only vehicle development but also many issues related to markets, infrastructure, legal considerations and certification. In this sense, EUROFAR is similar in scope to the NASA/Bell-Boeing exercises which commenced in 1985; however, it is different in that it is conceived from the outset as a multi-national and essentially civil aircraft development programme. The first vehicles should commence construction in the late 1990s, with delivery by 2001.

FIGURE 6
EUROFAR MANAGEMENT AND ACTIVITIES STRUCTURE


Industrial management committee
Note: AS, Aerospatiale; WH, Westland Helicopters: AG, Agusta; AIT, Aeritalia
AS
Industrial program group
Vehicle project team
AG
AS
Market survey
MBB
ATC & infrastructure
WH
Certification
AG
Cost & planning
WH
Legal matters
AG
Special applications
Rotor
MBB
Propulsion
MBB
Structure
AIT
Flight controls
AS
Avionics & cockpit
AS
Basic equipment
AG

Other Programmes

In addition to the programmes mentioned above, there exist several other development programmes involving advanced rotorcraft being undertaken by a number of other organizations: Magnum T/R, Ishida Corporation, European Helicopter Industries (EHI), McDonnell-Douglas Helicopter Company, Sikorsky Helicopter, etc.

- Magnum T/R is a US company organized to develop and produce a civil modification of the XV-15;
- Ishida Corporation is a Japanese-financed aircraft manufacturer currently developing a tilting wing aircraft concept in the US, referred to as a Dual Mode Air Vehicle (DMAV), in corporate and commuter configurations.
- Helicopter manufacturers such as EHI (a consortium of Westland and Agusta), Sikorsky and McDonnell-Douglas are all developing advanced helicopter concepts with some of the enhanced performance characteristics of CTR;
- Reports from the former USSR indicate that the Soviet aviation industry has tested two tilt-wing aircraft prototypes which are claimed to be in advance of the V-22 programme in terms of eventual delivery to the market place.

1.3.2 Vertiport Siting Requirements and Planning Studies

The civil applications of tiltrotor technology will derive their greatest benefits by operating within an air transportation system designed to exploit the enhanced in-flight performance of the tiltrotor vehicle. The development of a network of "vertiports", which would be sited, planned and designed to take advantage of the aircraft's capabilities, was deemed to be critical to the benefits and success of CTR. It also became apparent that, in the real world, the development of specific vertiport sites for tiltrotor operations would likely require considerable lead time for land acquisition, planning and design, environmental review, permits and approvals, construction, certification, etc. Accordingly the FAA is now actively pursuing a programme of site selection and feasibility studies similar to those of the NYNJ Port Authority. The agency has addressed a public invitation to different states, local authorities and foreign countries. More specifically, the FAA is providing financial assistance under the Airports Improvement Program (AIP) to those states and authorities which responded to this invitation by undertaking such studies.

According to our research to date, the FAA has awarded grants for a total of approximately 2.6 million dollars (US). These grants range from $600 000 for region-wide studies performed by the PANYNJ, to $65 000 for smaller studies. Objectives vary from the study of the demand for leisure travel in Florida to the study of access to remote areas in Alaska. Details on objectives, duration of programme and resources involved in various site studies are found in Appendix 6.

1.3.3 Vertiport Infrastructure and Air System Requirements Programmes

In parallel with the other two programme categories discussed previously, a substantial amount of work has been done on air navigation systems and infrastructure requirements. In August 1988, the FAA and the industry (represented by organizations such as the American Helicopter Society, Boeing Helicopter, and various consultants, etc.) joined together to form the FAA/Industry Vertiport Working Group. The objective of the group was to complete a vertiport planning guide by the end of 1989. As of January 1990, a draft Advisory Circular (FAA reference 150/53xx-xx) has been developed for provisional planning purposes, although a number of issues continue to generate debate:

> (1) Vertiport size: should consideration be given to a minimum facility with no STOL capability or a combination of a minimum facility with a specific recommendation for fixed length clearance and/or minimum runway;
>
> (2) Airspace requirements: should the development of CTR standards be based on current fixed-wing aircraft criteria, helicopter criteria or, because of the unique capability of the CTR, should a new set of criteria be developed.

At another level, the FAA is also conducting a number of critical tiltrotor/vertiport planning and development activities. The FAA's program objective is to develop a National Civil Tiltrotor Implementation Plan for the integration of CTR into the national air transportation system. The FAA expects to produce a national planning document by June 1990. Also, the FAA has created a rotorcraft task force composed of industry representatives. Its mandate is to direct a series of development projects regarding not only tiltrotor technology in particular, but rotorcraft technology in general. These projects include: Low Altitude CNS B/C Analysis, IFR Operations Evaluation, Obstruction Avoidance, ATC Procedures, Simulation Standards, Display and Control Studies, Heliport/Vertiport Design and Planning, Voice Technology (to start in 1991) and Rotorcraft Separation Standards. These activities, as well as others which have not been mentioned in this text, demonstrate the extent of the scope of work involved in the research and implementation of the civil application of the tiltrotor technology.

2. CTR VEHICLE DESCRIPTION

As described in the previous chapter, tiltrotor technology was developed in response to requirements for a vehicle which would combine the vertical flight, hovering and maneouverability of helicopters with the cruising speed, range and fuel economy of fixed-wing aircraft.

At present, certain aspects of the technology are still in the developmental and testing phases. For the purposes of the present volume, therefore, the description of the capabilities and characteristics of the CTR vehicle presented in this section is based largely on information available for the two models currently flying: the Bell XV-15 test aircraft and the Bell-Boeing V-22 Osprey military development aircraft.

It might be mentioned that the V-22 not only represents the current state-of-the-art aircraft in terms of tiltrotor technology, but also incorporates a number of other advanced aeronautical design features:

- extensive use of composite materials, such as graphite-epoxy solid laminates;
- articulating wingtip rotor and nacelle assemblies;
- fly-by-wire flight control systems;
- fixed-wing maintenance concept;
- improved cockpit and avionics systems.

2.1 Basic Technology and Modes of Operation

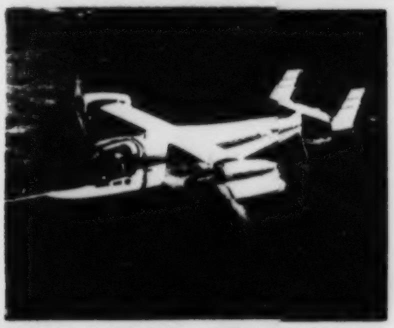
The basic and unique feature of tiltrotor technology lies in the ability of the aircraft to make a rapid airborne conversion between helicopter and airplane modes of operation. This is made possible by the use of the two large proprotor assemblies, mounted at the wingtips, which can be rotated through an arc greater than 90 degrees relative to the alignment of the fuselage: from a vertical helicopter rotor position to a horizontal conventional airplane propeller position or vice versa.

In the V-22 the rotors are synchronized by means of an interconnect transmission shaft that runs through the wing between the two nacelle-mounted transmissions. This shaft also provides power transmission from one rotor system to the other in case of an engine failure.

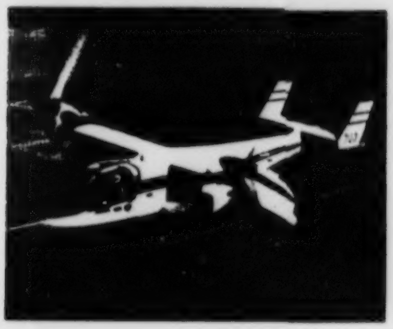
As shown in Figure 7, with an example of the XV-15, the vehicle can operate in three basic modes: helicopter, transition and airplane, as described in the following paragraphs.

FIGURE 7
BASIC MODES OF TILTROTOR FLIGHT

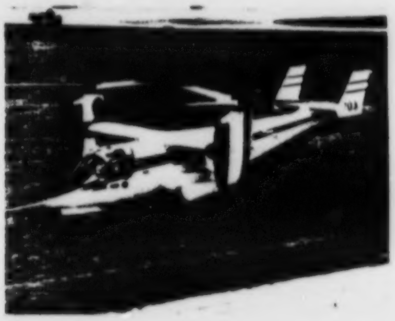
AIRPLANE MODE: STANDARD LEVEL FLIGHT



TILTROTOR MODE: TRANSITION STAGE



HELICOPTER MODE: VERTICAL FLIGHT



Helicopter Mode

In this mode, the proprotors and nacelle assemblies are positioned vertically with respect to the fuselage. The aerodynamic lift developed by the aircraft in this mode is entirely propulsive. The lift is generated by air flowing over the rotating proprotor blades. These are designed with a higher degree of twist than in the case of the larger helicopter rotor blades, in order to maximize lift efficiency. Flight control in this mode is accomplished using conventional helicopter procedures. In addition to vertical landing and take-off operations, the helicopter operational mode permits the tiltrotor to hover in a stationary airborne position or to accelerate forward through 150 knots or to move sideways or backward at more than 35 knots.

Transition Mode

In the transition (tiltrotor) mode, the pilot automatically controls the transition from the helicopter system to the airplane control system. The movement of the nacelles from vertical position to horizontal position lasts some 10-15 seconds. During this conversion period, the aircraft speed increases and lift is transferred from the rotors to the wings. At the same time, the direction of flight is gradually changed from vertical climb to level horizontal flight. Unlike the fuselage of a fixed-wing aircraft, which changes pitch during take off, the tiltrotor fuselage can remain level during the transition mode.

Airplane Mode

When cruising like a turboprop in the airplane mode, lift for the tiltrotor is provided by air flowing over the wings and forward propulsion is provided by the high-twist proprotor blades, which act as highly efficient propellers. Current tiltrotors (XV-15 and V-22) can fly at some 300 knots (twice as fast as a helicopter) and deliver equivalent payloads on approximately half the amount of fuel consumed by helicopters on flight stages greater than 185 km. In this mode, the pilot controls the CTR aircraft in much the same way as a conventional turboprop airplane.

STOL Mode

The ability of the tiltrotor to tilt its proprotors and engines to different angles also makes it possible for the vehicle to operate as a short take-off and landing (STOL) aircraft. Proprotor tilt angles of 60 to 70 degrees produce lift from both the propotors and wings. In this STOL mode the tiltrotor vehicle can carry either heavier payloads or more fuel, to extend its range over longer distances than in the VTOL mode.

2.2 Vehicle Configurations

The only examples of tiltrotor technology currently flying are the US XV-15 test aircraft and V-22 Osprey military aircraft. Although neither of these was explicitly designed for civilian missions, it can be assumed that civil versions of tiltrotor aircraft will incorporate all of the necessary amenities: adequate headroom, carry-on baggage storage, comfortable seat pitch, environmental control, galleys and lavatories. The civil application of tiltrotor technology involves a different set of objectives from those for military application. As an example, the 1987 NASA/Bell-Boeing **CTR Missions and Applications Study** identified the following guidelines for the design of eventual civil-use vehicles.

- V-22 technology base or derivatives:
  - twin engines
  - composite airframe structure
  - tilting wingtip mounted rotors
  - fly-by-wire
  - advanced cockpit displays
- 600 nm design range, using vertical take-off with one engine inoperative (OEI Hover)
- 800 nm design range, with rolling take-off from a 750 ft field (STOL)
- Commuter mission profile with FAR reserve fuel requirements
- All federal aviation regulations met for safety, including Category A operations
- Ramp self-sufficiency: airstairs, APU, powerpack
- 30 seconds emergency excess power rating for the purpose of recovery from single engine failure (OEI)
- Pressurized fuselage
- Normal passenger accommodations and amenities:
  - seating at 30 inch pitch
  - lavatories and galley (hot meal with beverage)
  - full cabin pressurization, heating and air conditioning.

These design guidelines were developed on the basis of experience with the V-22 aircraft, commercial aircraft design experience, FAA regulations and input from airlines and other aviation operators. A number of other proposed civil configurations for tiltrotor technology have come forth in recent years (see Figure 8). The above-mentioned 1987 study for instance, identified a number of possible tiltrotor configurations, each geared towards a specific civil aviation market application. In addition to the NASA/Bell-Boeing team, other groups have proposed their own configurations, based on their perceptions of the market and the development of the technology. The following proposals for specific CTR vehicles are grouped as: (1) derivatives of the V-22 Osprey; (2) new configurations identified in the 1987 NASA/Bell-Boeing study; (3) configurations proposed by other groups.

2.2.1 V-22 Osprey Derivatives

Out of the six CTR configurations proposed by NASA/Bell-Boeing, three are derivatives of the military V-22 technology base (Figure 9).

The V-22 derivative design which involves a minimum of changes (vis-a-vis the Osprey) is the **CTR-22B**. This derivative retains the V-22 drive train and primary structure and has a non-pressurized fuselage. A passenger interior with three abreast seating, lavatory, galley, windows and doors is added in replacement of military equipment. The CTR-22B meets the civil design range requirement of 600 nm, has updated transmission and carries 31 passengers.

The **CTR-22C** would have a V-22 drive train and a new, larger, pressurized fuselage. It would carry 39 passengers seated three-abreast, with luggage carried inside the fuselage rather than in outboard sponsors as in the CTR-22B.

The **CTR-22D** would be similar to the CTR-22C except that the larger four-abreast fuselage would permit seating capacities up to 52 passengers. With a 39 passenger load, the design range would be approximately 600 nm; with a maximum load of 52 passengers, the range would drop to 280 nm.

2.2.2 NASA/Bell-Boeing Advanced Designs

In addition to the direct V-22 derivatives, the above-mentioned study also proposed three "All-New" pressurized configurations (Figure 10). These would, however, use the basic structural design concept and propulsion systems as for the V-22 Osprey.

The **CTR-800** would be approximately the same physical size as the XV-15 and would combine a new high-wing design with a pressurized fuselage. A total of 8 passengers would be seated in an executive-style interior.

The **CTR-1900** design, which resulted from a market study that compared various combinations of main wing and tail configurations, incorporates a low wing, "V" tail and canards, and carries 19 passengers.

FIGURE 8
CTR CONFIGURATIONS

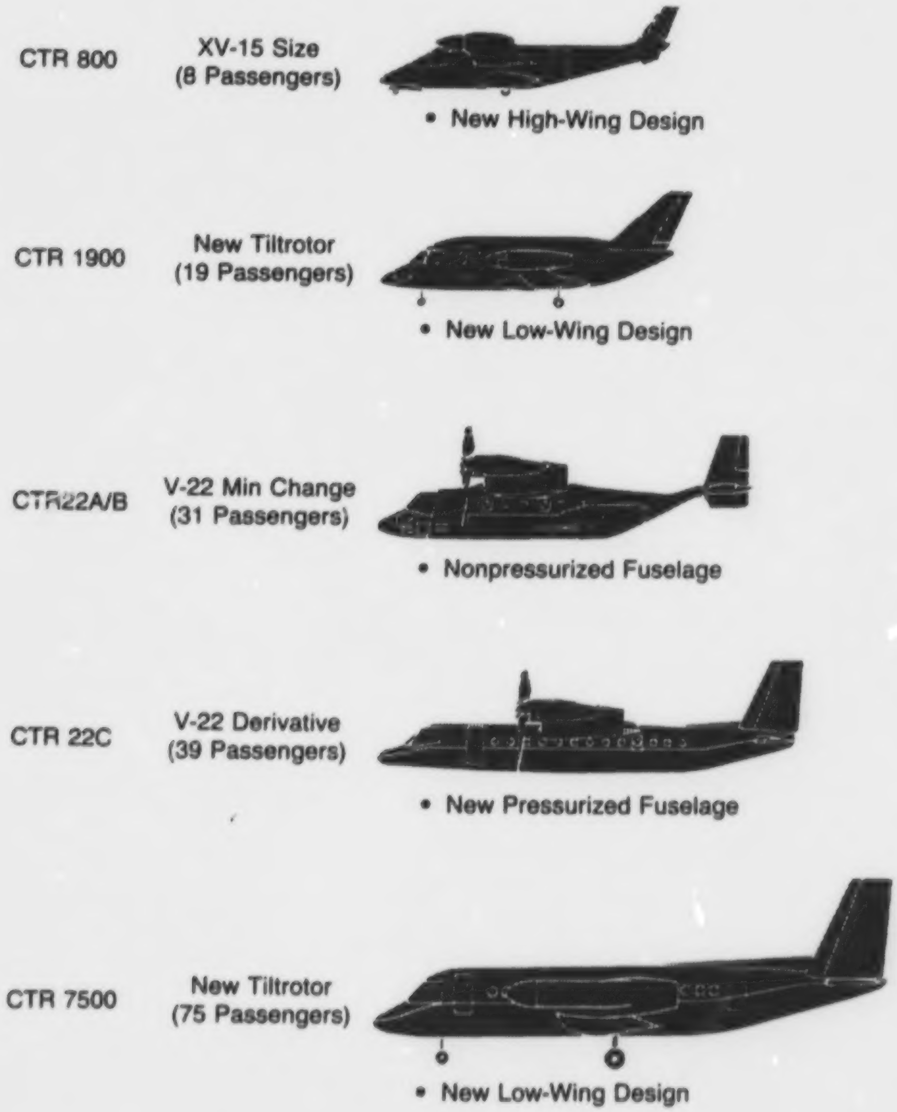
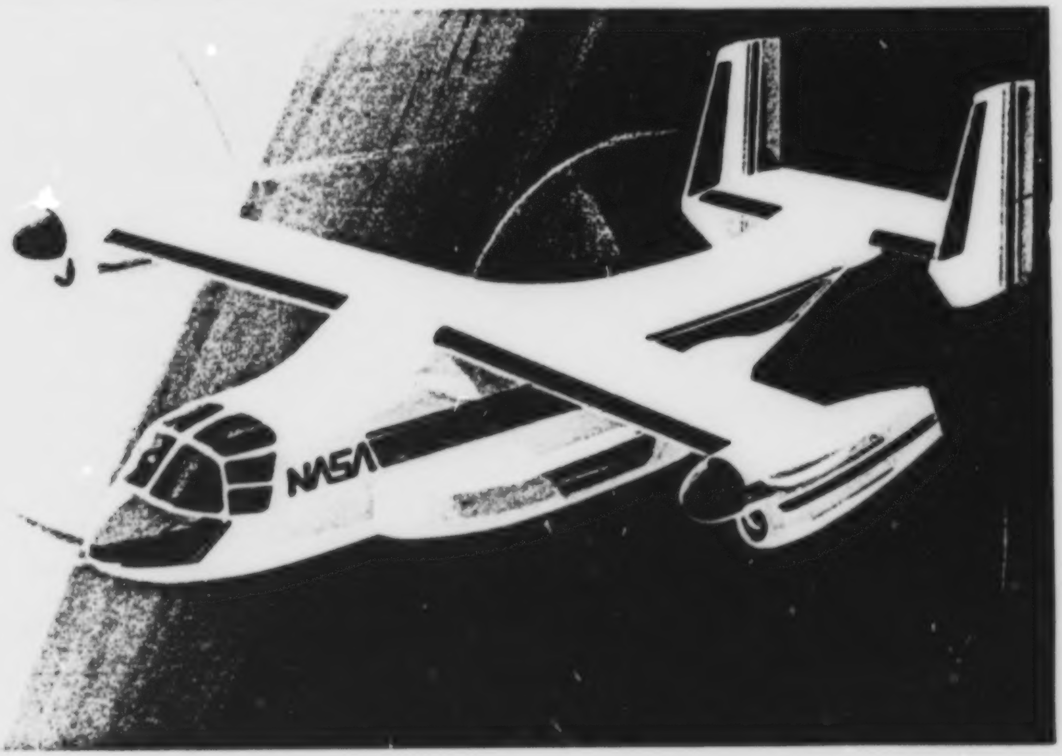

CTR 800
XV-15 Size
(8 Passengers)
• New High-Wing Design
CTR 1900
New Tiltrotor
(19 Passengers)
• New Low-Wing Design
CTR22A/B
V-22 Min Change
(31 Passengers)
• Nonpressurized Fuselage
CTR 22C
V-22 Derivative
(39 Passengers)
• New Pressurized Fuselage
CTR 7500
New Tiltrotor
(75 Passengers)
• New Low-Wing Design

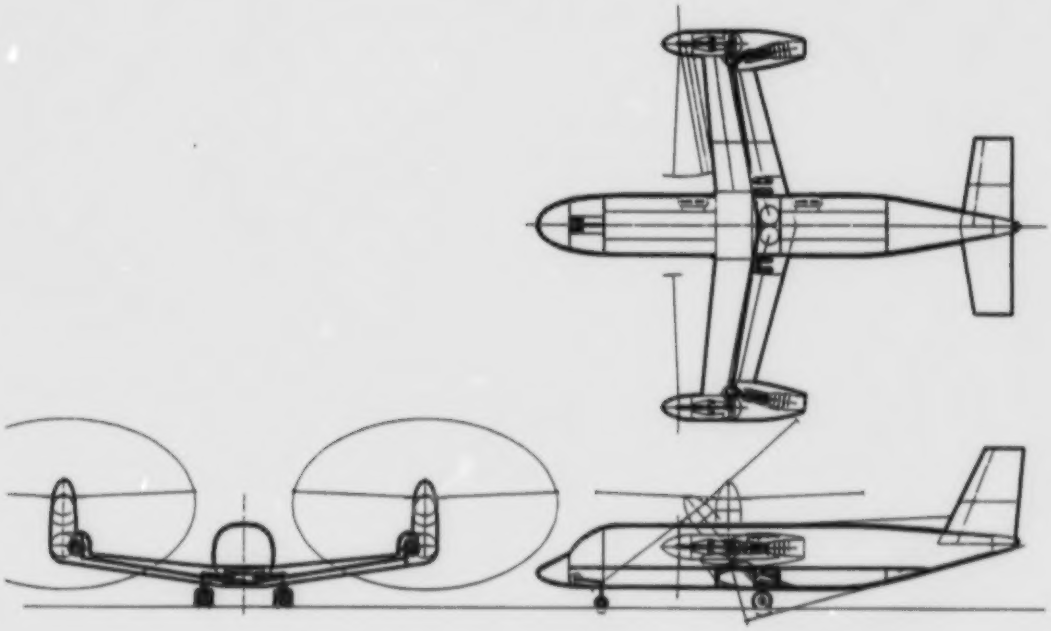
FIGURE 9
V-22 OSPREY DERIVATIVES - AIRCRAFT CHARACTERISTICS



	CTR-22B	CTR-22C	CTR-22D
No. Passengers	31	39	52
Overall Length (ft)	57.3	68.6	71.7
Wing/Rotor Span (ft/ft)	45.8/38.0	45.8/38.0	48.0/38.0
TOGW (OEI Hover) (lb)	45,120	46,230	49,260
Cruise Speed (kt)	240	282	282
Range (nmi) (OEI Hover)	600	600	280*
Engine	T406	T406	Growth T406
Takeoff Engine Rating (HP) 30 sec Emergency Rating (HP)	6805 8506	6805 8506	7312 9140

* 600 nmi with 39 passengers

FIGURE 10
NASA/BELL - BOEING ADVANCED DESIGNS - AIRCRAFT CHARACTERISTICS



CTR-7500

	CTR-800	CTR-1900	CTR-7500
No. Passengers	8	19	75
Overall Length (ft)	41.5	46.6	83.7
Wing/Rotor Span (ft/ft)	32.2/26.0	37.0/28.0	63.0/46.0
TOGW (OEI Hover) (lb)	15,750	22,800	79,820
Cruise Speed (kt)	273	283	300
Range (nmi) (OEI Hover)	600	637	600
Engine	RTM 322 + 14%	Scaled RTM 322	Growth T406
Takeoff Engine Rating (HP) 30 sec Emergency Rating (HP)	2100 2625	3440 4300	12,883 16,100

Of all the models studied, the **CTR-7500** was the largest in terms of seating capacity (75). Passenger seating would be five-abreast; an alternative design would carry the same number of passengers in a six-abreast arrangement. Further study, however, would be required in order to improve the design (optimum fuselage and determination of engine types). Like the CTR-1900, the CTR-7500 incorporates a new low-wing design.

Mention should be made that because of the low-wing arrangement, both the CTR-1900 and CTR-7500 do not use tilting engines. Only the main rotor assemblies themselves rotate during conversion between vertical and horizontal flight.

2.2.3 Other Proposals

In addition to the above-mentioned configurations, a number of other models have been proposed by other groups. These are summarized in the following paragraphs and illustrated in Figures 11 and 12.

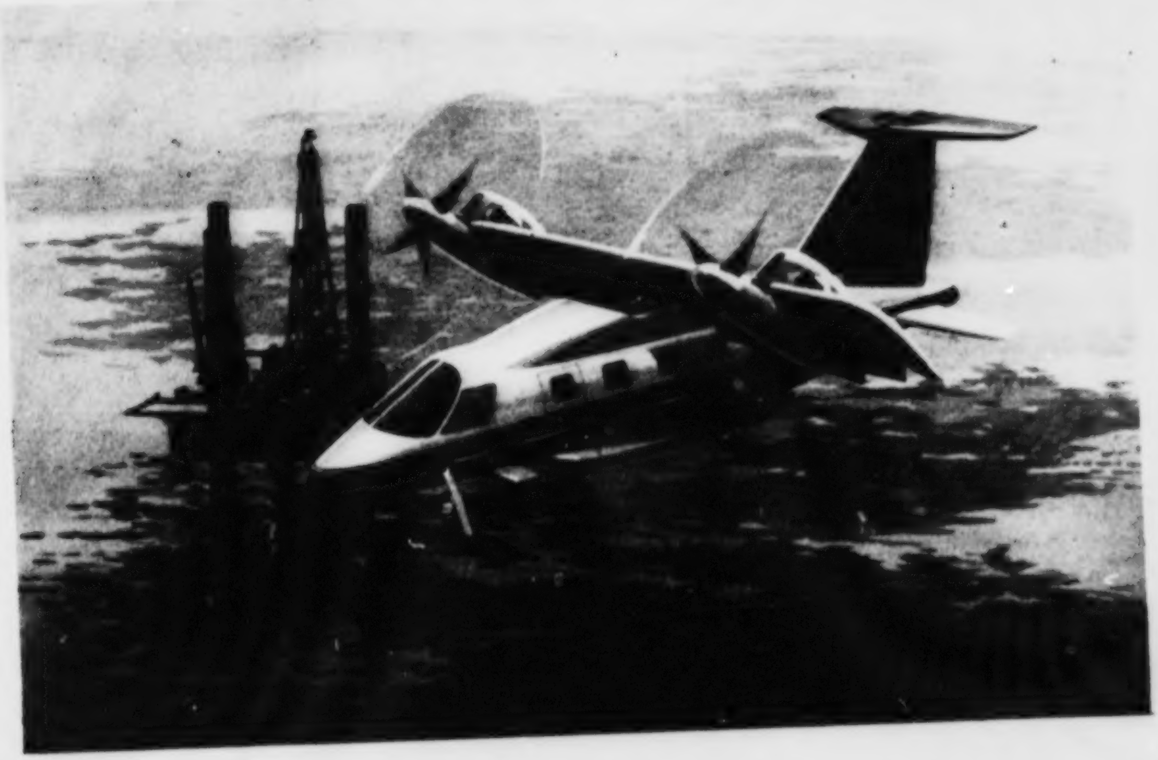
The **Ishida TW-68** is a tilting-wing design, with a capacity of from 9 to 16 passengers, depending on whether it would be deployed in a corporate, commuter or maximum-capacity configuration. The company refers to the aircraft as a dual mode air vehicle (DMAV) shuttle aimed at the corporate/commuter/ express delivery market niches.

To assist in further studies the **EUROFAR** group has developed a baseline configuration, illustrated in Figure 13, capable of carrying approximately 30 passengers with three-abreast seating. In this design, only the rotor blade and axle assemblies would rotate, while the wing-tip nacelles would remain in the same alignment relative to the fuselage.

The US **Magnum MTR-201** is a proposed aircraft with a 9-passenger seating capacity and a 1000-mile range. The design would apply the Bell XV-15 flight dynamics to a Mitsubishi MU-2 fuselage.

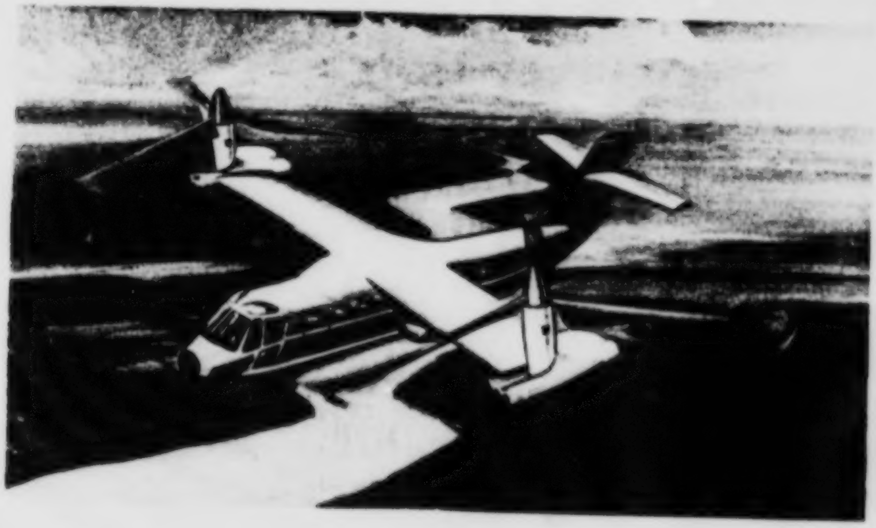
Finally, in a related area, the Bell-Boeing consortium has also developed a tiltrotor unmanned air vehicle, the **Pointer UAV**, patterned after the V-22. This programme is privately funded by the companies and is intended to respond to the world-wide demand for low-cost, versatile UAV's. First flight took place in 1988.

FIGURE 11
ISHIDA CORPORATION TW-68 - AIRCRAFT CHARACTERISTICS



Dimensions and Areas		
Wing Area	255 Sq. Ft.	(23.7 M^2)
Wing Span	36 Ft.	(10.97M)
Wing Chord	7.08 Ft.	(2.16M)
T/C Ratio	20%	
Length	39.38 Ft.	(12M)
Height	13.40 Ft.	(4.08M)
Interior Width	64"	(1.62M)
Cabin Length	15.83 Ft.	(4.82M)
Cabin Height	63"	(1.6M)
Design Conditions (Projected)		
Max Speed	350 KTS	(646 Kmh)
Max Cruise	268 KTS	(495 Kmh)
Best Range	187 KTS	(345 Kmh)
Best Endurance	170 KTS	(314 Kmh)
Weights		
Max T.O. STOL	16,500 Lbs.	(7,483 Kg.)
Max T.O. VTOL	12,500 Lbs.	(5,669 Kg.)
Passenger Capacity		
Corporate Configuration	9	
Commuter Configuration	14	
Max Passengers	16	

FIGURE 12
EUROFAR - 30 PASSENGER BASELINE CONFIGURATION



▪ Maximum AUW		13650 kg
▪ Empty Mass (fully equipped)		8750 kg
▪ Empty Mass/Max. AUW		64.1 %
▪ Cruise Speed		300/335 kts
▪ Cruise Conditions		7500 m/ISA
▪ Wing Span		15.3 m
▪ Fuselage Length		19.4 m
▪ Rotor Diameter		11.21 m
▪ Engines:	Number Type MCR at SL/ISA	2 TBD 2570 kW

2.3 Basic Vehicle Operational Parameters

Tiltrotor aircraft are capable of making vertical, nearly vertical, or extremely short rolling take-offs and landings. They have a range of about 600 nm (even higher if the vehicle executes a rolling take-off and landing) and a cruising speed of between 240 and 300 kts, depending on the configuration. On the ground, the CTR aircraft will maneouver on wheels in and out of the gate under its own power. Most of the tiltrotor aircraft presently under consideration for civil application are designed to operate at cruising altitudes between 16 000 feet and 22 000 feet. This corresponds roughly to the operational altitudes of today's turboprop aircraft. Smaller versions of these vehicles would be limited to cruise altitudes below 12 000 feet. The present section of this report provides a description of CTR aircraft with respect to those critical parameters which have a direct impact on requirements for the following aspects of the CTR air transportation infrastructure:

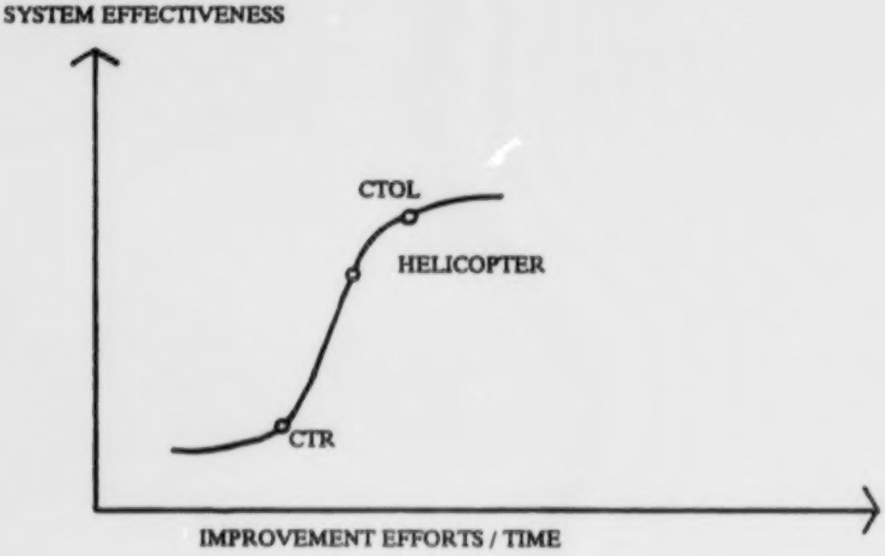
- airspace requirements
- vertiport facilities

More particularly, this section attempts to consider these parameters from the point of view of both short-term and long-term planning perspectives. In the short term, requirements will reflect the parameters of vehicles such as the Bell-Boeing V-22, Ishida TW-68, EUROFAR baseline configuration or other CTR aircraft currently under development. In the context of long-term planning of the infrastructure and facilities needed to support CTR operations, it will be necessary to consider the potential technological, engineering and operational improvements which will take place after the first generation of CTR vehicles enters regular service.

Considering the relative position of CTR technology vis-à-vis that of helicopters and conventional aircraft on the typical "S" curve of the general pattern of technological development (Figure 13), our long-term view must not be overly influenced by the operational limitations of the CTR vehicles currently being developed. One must look beyond the capabilities of the first generation of CTR and properly integrate foreseeable improvements of CTR technology into the long-term planning process in order to capitalize on the special inherent characteristics of this technology. The same attitude must be applied when considering the necessary technological advancements of other related components of an eventual CTR air transportation system such as the development of advanced navigation aids.

In order for CTR technology to contribute to the enhancement and efficiency of the air transportation system of the 21st century, it must ultimately be capable of operating in IFR conditions (near-zero visibility, etc.), in the constrained airspace usually associated with urban

FIGURE 13
GENERAL PATTERN OF TECHNOLOGICAL DEVELOPMENT



vertiport sites and at locations which are attractive from an air passenger market point-of-view. In order to minimize vertiport land and airspace requirements, CTR will have to be able to operate safely from minimum vertiport facilities (zero field length) and satisfy FAA Transport Category A requirements.

Recognizing the ultimate role of CTR services at an early stage of system development and properly incorporating future requirements into the long-term planning process will enable appropriate sites within cities to be safeguarded with minimum public investment, by encouraging urban development compatible with vertiport operations. The following pages summarize the basic parameters of various CTR models currently under consideration by U.S., European and Japenese manufacturers. These vehicles form the basis for development of CTR planning parameters and estimation of CTR market potential in Canada. Further details on each aircraft are available in Appendix 2.

2.3.1 Aircraft Size

From the point of view of facilities planning for tiltrotor operations, the critical vehicle parameters are related to aircraft geometrics, payload, capacity and maximum weight of the aircraft as summarized in Table 3.

TABLE 3
CTR AIRCRAFT CHARACTERISTICS

Aircraft Model		Passenger Capacity (seats)	Cargo Capacity (cu. ft)	Fuel Capacity (gal US)	Length (ft)	Width(1) (ft)	Height (ft)	TOGW (lbs)
Bell-Boeing	CTR-22B	31	n.a.	1423	57.3	84.6	17.6	45 120
	CTR-22C	39	254	1423	68.6	84.6	20.6	46 230
	CTR-22D	52	n.a.	1485	71.7	86.0	23.3	49 260
	CTR-800A	8	32	433	41.5	58.2	15.3	17 216
	CTR-1900	19	76	474	46.6	65.0	17.0	22 800
	CTR-7500	75	n.a.	1860	83.7	109.0	27.9	79 820
EUROFAR	baseline	30	n.a.	n.a.	63.6	86.9	19.7	30 092
Ishida	TW-68	9-16	n.a.	n.a.	39.4	36.0	13.4	12 500
Magnum	MTR-201	9	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

(1) Wing span and rotor diameter

2.3.2 Hovering Ability

The ability of VTOL vehicles (helicopters, tiltrotors and other rotorcraft) to remain stationary relative to a point on the ground while airborne is referred to as hovering. In order to hover, the tiltrotor must operate in helicopter mode. As for any rotorcraft, its capability to hover is limited by a number of factors. In particular, the mix of vehicle gross weight, pressure altitude and ambient temperature (WAT) limits the operational ceiling at which the vehicle can remain aloft in stationary hover.

Hover (and vertical climb) operations are the most demanding tasks for rotorcraft in general. They require maximum engine power output and generate maximum disk loading. As a consequence, they have a direct impact on fuel consumption and maintenance cost. In a typical operation they represent the most expensive phase of the flight, although in a typical CTR mission these operations would represent a small fraction of the total flight time (some 1-2 min.). Depending on the total engine power requirements, two types of hover operations are recognized:

(1) Hover in ground effect (HIGE)
(2) Hover out of ground effect (HOGE)

Hovering in the proximity of the ground (1.5 times the rotor diameter above ground level) has a positive effect on lift capability and reduction of induced drag in comparison with hovering outside the proximity of the ground. As a result, HOGE requires greater power than HIGE. The HIGE power requirement is generally calculated by taking 90% of the power required to maintain HOGE.

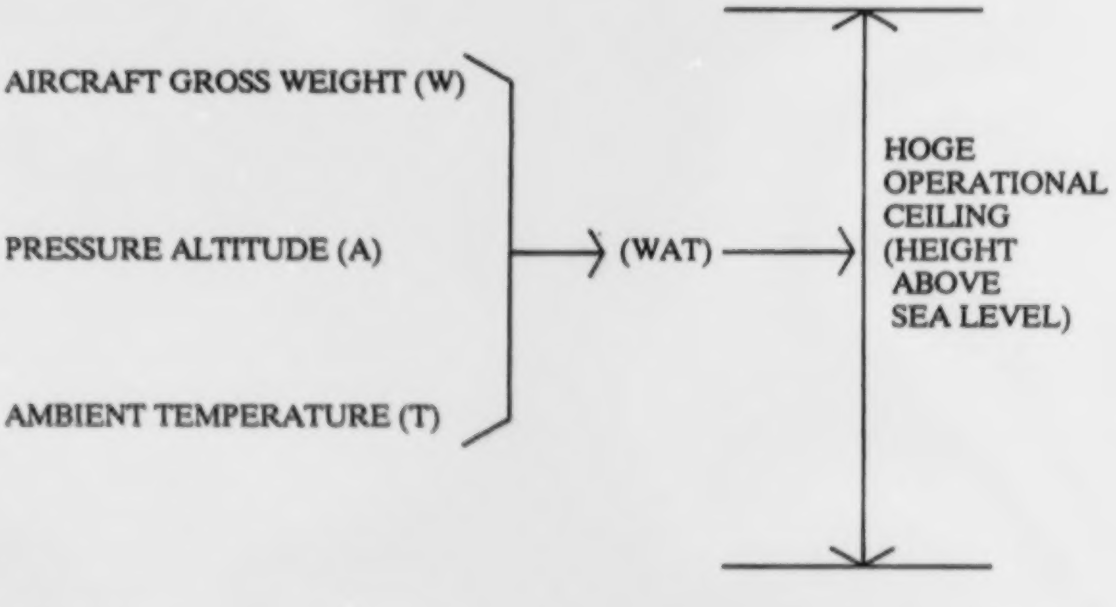
Since the ability of rotorcraft to maintain hover out of ground effect is limited by certain specific WAT conditions, manufacturers generally indicate the HOGE capability of the vehicle in terms of maximum HOGE altitute for the assumed ambient conditions. The Table 4 summarizes HOGE limits of current CTR models in terms of permissible altitude at standard temperature, taking into account the maximum take-off gross weight of the aircraft (MTOGW).

The HOGE limit constitutes the operational ceiling altitude of a specific tiltrotor vehicle with respect to hover or vertical climb/descent manoeuvers. In terms of access to specific vertiport sites by tiltrotors using vertical take-off and landing procedures, therefore, the ground altitude of the site in relation to the vehicle HOGE altitude limit and the heights of surrounding objects will determine the limiting operational environment for the vehicle.

TABLE 4
HOVER OUT OF GROUND EFFECT: LIMITS OF CURRENT CTR VEHICLES

		altitude ASL	
		(metres)	(feet)
Bell-Boeing	MV-22	1354-2092	4400-6800
EUROFAR	baseline	3 000	9 850
Ishida	TW-68	n.a.	n.a.
Magnum	MTR-201	n.a.	n.a.

FIGURE 14
HOVER OUT OF GROUND EFFECT: FACTORS LIMITING OPERATIONAL CEILING


AIRCRAFT GROSS WEIGHT (W)
PRESSURE ALTITUDE (A)
AMBIENT TEMPERATURE (T)
(WAT)
HOGE OPERATIONAL CEILING (HEIGHT ABOVE SEA LEVEL)

---

* for a given engine power;

In the context of inter-city services linking urban downtown sites, it is assumed that in situations where vertical IFR take-off and landing procedures are the only way to access a particular vertiport due to airspace limitations, a height of 1000 ft. above ground level represents the maximum height from which vertical descent would have to be initiated, taking into account the likely maximum heights of surrounding obstacles in such areas, according to typical municipal zoning ordinances and existing structures.

For the purposes of the present report, a number of Canadian cities were examined to determine the technical feasibility of vertical take-off and landing procedures solely from the point of view of the HOGE limit. This information is presented in Table 5, which indicates that CTR aircraft with HOGE limits in the 3000 m range could perform vertical manoeuvers in the vicinity of 1000 ft. obstacles at major Canadian urban centers with no payload penalties. At certain remote sites (in the Rocky Mountains, for instance) vertical take-off and landing operations might require payload or range penalties depending on the specific site reference elevation, ambient temperature and height of surrounding obstacles.

TABLE 5
GROUND ELEVATIONS OF THE SELECTED CANADIAN AIRPORTS

Site	Ground reference elevations (metres)	Ground reference elevations (feet)	Available height above ground at 3000 m HOGE limit (metres)	Available height above ground at 3000 m HOGE limit (feet)
Toronto/Island	76	251	2924	9592
Toronto/Pearson Int'l	173	569	2827	9274
Montreal/Cartierville	37	120	2963	9723
Montreal/Dorval	36	117	2964	9726
Montreal/Mirabel	82	270	2918	9573
Montreal/St-Hubert	27	90	2973	9753
Vancouver/Int'l	3	9	2997	9834
Vancouver/Harbour Heliport	1	2	2999	9841
Ottawa/Int'l	114	374	2886	9469
Ottawa/Rockcliffe	57	188	2943	9655
Quebec City	74	243	2926	9600
Quebec City/Charlesbourg	20	66	2980	9777
Calgary/Int'l	1084	3557	1916	7927
Edmonton/Int'l	723	2373	2277	7470
Edmonton/Municipal	671	2200	2329	7643

2.3.3 One Engine Inoperative Procedures

Since safety and, most particularly, the avoidance of catastrophic accidents is of paramount importance in civil air transport, the tiltrotor aircraft will have to be capable of maintaining operations after suffering a total sudden engine failure following which the pilot must be able to fly the vehicle to a safe landing.

For use in public transportation, CTR aircraft must demonstrate performance levels in accordance with FAA certification requirements as specified under Transport Category A. According to these regulations, if one engine fails at any time after start of take-off, the vehicle must have the ability to perform the following manoeuvers with the remaining power available:

(1) return and land safely

or

(2) continue the take-off and climb out of ground effect (OGE) at a minimum rate of 100 ft/min.

These are illustrated in Figure 15. If sufficient height is available, the preferred method would be to tilt the thrust vector forward, make a transition to STOL flight, and subsequently land at a suitable conventional or STOL airport. The more critical engine failure, in terms of both aircraft handling and thrust requirements, occurs when the option of making the transition to STOL flight is not available, thereby requiring immediate initiation of a vertical landing.

According to EUROFAR sources, simulation studies have established that an emergency OEI fly-away or safe-landing procedure would not require more than 30 seconds for an assumed decision height. The 30-second OEI rating therefore became the basic engine design parameter for this vehicle. This "time" rating ensures that in case of a single engine failure, the remaining engine will be able to provide increased power for a minimum of 30 seconds in order to compensate for the loss of the other engine and enable the vehicle to perform all certified operations with only one engine operative. It is estimated that the emergency power requirement will exceed the maximum cruise power rating by a factor of at least 40%.

It should be noted that the OEI time rating (e.g. 30 seconds) refers to a specific critical decision point height above ground level: i.e. the height from which it will take 30 seconds to safely return to a clear area on the ground. The rating of 30 seconds corresponds to a CDP height limitation of 100 - 150 ft.

Such a limitation is open to serious question. A review of available literature on CTR technology and its commercial potential did not reveal any references to specific studies to determine any optimum or desirable CDP height for safe operations in and out of vertiports in constrained urban environments. The 30 second OEI rating and its CDP height may limit the potential applications of CTR in the constrained airspace environment typical of central business districts of large cities, which represent the key target markets of this service.

Considering the typical heights of downtown skyscrapers, CDP elevations significantly higher than those associated with the 30-second OEI rating may be appropriate: up to 1000 feet in some cases. If such a CDP height is eventually adopted as a system planning parameter, then the emergency rating of the engines would have to be increased to perhaps 1.5 to 2 minutes in order to permit safe OEI procedures from such a height. The obvious implications of such an increase in OEI performance would be a corresponding increase in capital, operational and maintenance costs of the vehicle, especially with regard to the engine component.

Potential for Rocket Assisted Take-off (RATO)

To obviate the requirement for excessively large engines which have the required thrust reserve such that a single engine can be utilized for a vertical descent/touchdown, there is a possibility that rocket assistance could be utilized to provide a large percentage of the weight support thrust requirement, and the normal engine thrust be utilized for descent rate variation and height control. The concept of the old rocket assisted take-off (RATO) comes to mind, coupled with the technology developed for the moon landing/take-off vehicle - which was a vertical descent of prolonged nature.

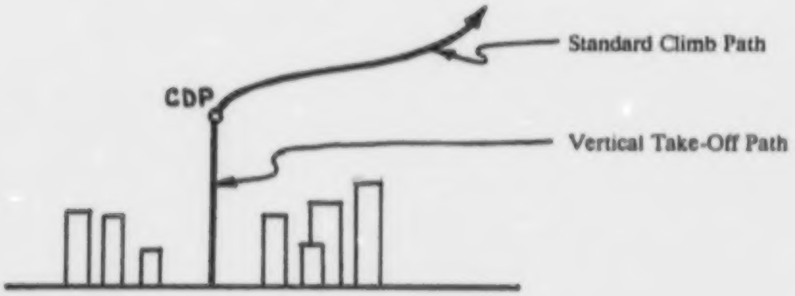
2.3.4 Climb / Descent

CTR climb and descent performance is described in the form of maximum take-off and descent angles, which are the direct result of particular combinations of vertical and horizontal (forward) speeds. The steepest angles are associated with the slowest forward speeds. True vertical climb and descent represent limiting cases of 90 degree angles and zero forward speed.

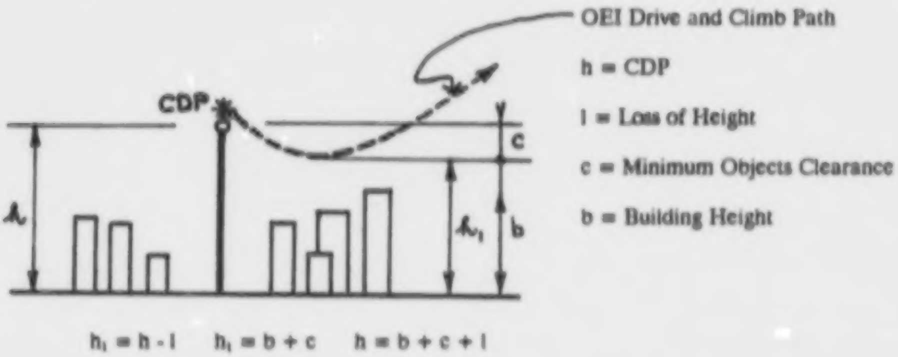
Currently there is no consensus on likely values for planning purposes concerning steep approach angles to be used during IFR tiltrotor operations. The FAA and NASA are in the process of testing approaches as steep as 25 degrees using a V-22 simulator at the Boeing Helicopter Philadelphia facility and actual V-22 aircraft at a number of sites. EUROFAR engineers have calculated a practical limit of 16 degrees as a design criterion for the EUROFAR reference vehicle. It has been suggested that approach angles of 25 degrees

FIGURE 15
CTR TAKE-OFF / OEI PROCEDURES

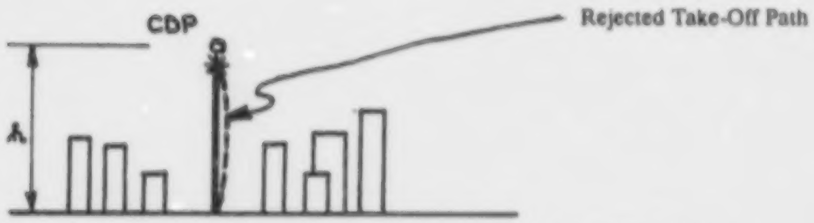
STANDARD TAKE-OFF / CLIMB PATH


CDP
Standard Climb Path
Vertical Take-Off Path

ENGINE FAILURE ABOVE CDP


OEI Drive and Climb Path
h = CDP
l = Loss of Height
c = Minimum Objects Clearance
b = Building Height
CDP
h
c
h_1
b
$h_1 = h - l$ $h_1 = b + c$ $h = b + c + l$

ENGINE FAILURE BELOW CDP


CDP
Rejected Take-Off Path
h

maximum h = Subject to the time rating of engine for OEI condition and more might be desirable in order to take full advantage of the essential potential benefits of tiltrotor technology vis-à-vis other modes of transportation.

The range of factors influencing the vertical speed component is different for climb and descent operations. The vertical climb speed is limited by aircraft design and available power-to-weight ratios, while the vertical descent speed tends to be limited by passenger comfort level during the landing procedure. While the climb operation requires more engine power output than does descent, it is the descent operation which is more sensitive to the steepness of the angle. Other pertinent factors include the desire of pilots to remain in view of the ground on landings and the power requirement of engines in order to overcome vertical descent velocities.

From the point of view of minimizing the required airspace around vertiports, true vertical operations are the most desirable. If engine power and OEI time ratings are sufficient to permit vertical take-offs and landings from points well above surrounding structures, then the problems related to steep-angles climb and descent manoeuvers are less of an issue. Due to considerations of operational economics, however, vertical landings and take-off, if feasible, would be executed only at sites where no other alternative is possible. Appendix 3 discusses the trade-offs between enhanced vehicle performance and reduced airspace requirements.

2.3.5 Range and Cruise Speed

Range and cruise speed are two closely related parameters. The physical limitation of turboprop technology currently limits the cruise speed of CTR aircraft to approximately 300-350 kts. This limitation combined with the market demand for the shortest possible door-to-door travel time limits the effective range of potential CTR services in the real world to approximately 350 nm. As the Table 6 indicates, the actual maximum range of current and planned CTR vehicles lies well beyond this limit.

2.3.6 Flight Envelope

The flight capability envelope (altitude vs airspeed) of CTR aircraft includes those of both helicopters and fixed wing vehicles, covering a range of operating speeds from 0 (hover) to approximately 350 kts. It is the lower speed limits of this performance range which are of interest with respect to potential benefits for safety, efficiency and capacity of the airspace architecture in the vicinity of vertiports.

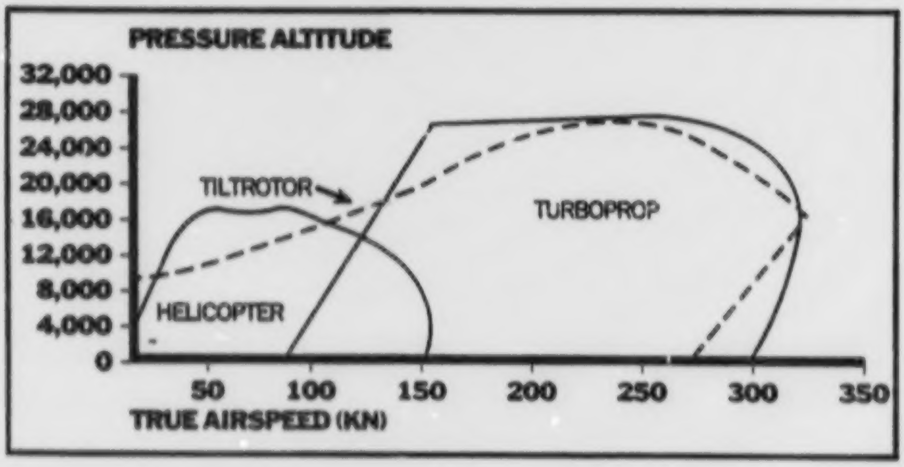
TABLE 6
CTR AIRCRAFT PERFORMANCE

Aircraft Model		Operational Range (nm)	Cruise Speed (knots)	Cruise Altitude (ft)
Bell-Boeing	CTR-22B	600	240	10 000
	CTR-22C	600	282	18 000
	CTR-22D	280	282	18 000
	CTR-800A	600	273	25 000
	CTR-1900	600	282	25 000
	CTR-7500	600	300	26 000
EUROFAR	baseline	665	335	24 600
Ishida	TW-68	700	268	n.a.
Magnum	MTR-201	865	350	30 000 +

This special ability to fly safely at low forward speeds or to perform stationary hover manoeuvers should prove to have a positive impact on the reduction of airspace requirement in vertiport control zones. When combined with appropriate navigation aids and advanced automated flight management systems, this ability should eventually permit not only straight-in approaches but also curved or even new concepts such as spiral and vertical approaches which would minimize the airspace required for CTR operations and enable otherwise inaccessible urban sites to enjoy direct intercity short-haul air service.

Substantial research in this area remains to be done in order to establish actual operational limits in this regard. This research must also address the possible effect of high-velocity winds and local gusts on slow-moving aircraft, a situation which may be frequently encountered in downtown areas with closely-spaced tall building structures.

FIGURE 16
FLIGHT CAPABILITY: TILTROTOR, HELICOPTER, TURBOPROP



3. OPERATIONAL PARAMETERS OF CTR AIR SERVICE

This chapter discusses CTR operations in terms of the critical parameters relevant to the planning and development of the infrastructure required to accommodate these operations. This includes (1) the key characteristics and objectives of the different types of CTR air services envisaged, (2) the performance and dimensional parameters of the aircraft and (3) the expected flight procedures.

3.1 Characteristics of CTR Air Service

The prime determinant for the definition of specific planning parameters and criteria for CTR air services lies in the nature of the specific services envisaged, in terms of their objectives, market orientation and resulting essential characteristics. The following pages summarize the specific characteristics and objectives of CTR air services (as opposed to other modes of transport), as they relate to the aeronautical infrastructure, vertiports and environmental impacts associated with such services. In general, the objectives and market orientation of CTR air services result from the ability of the VTOL vehicle to provide enhanced air transportation service, by combining vertical take-off and landing capability with horizontal flight efficiency:

(a) to provide air access to sites where service by conventional fixed-wing aircraft would be impossible, thereby permitting airport facilities to be located closer to their markets, thus enabling:
  - superior door-to-door level of service for air travellers by means of a reduction in the ground access times in relation to the total trip times;
  - access to remote sites where conventional airport construction is not feasible.

(b) to provide additional capacity within existing airspace by using the enhanced manoeuverability of CTR to take advantage of airspace not suitable for CTOL operations.

As elaborated in section 7.0 of this study, CTR technology could play a significant role in a number of applications in the air transport industry in Canada. On the basis of their basic market or orientation, these applications can be grouped into the following categories.

- air passenger service
- air cargo / package express service
- support of resource exploration/development
- corporate / executive air services
- public services

The focus of the present volume is to address the issues related to the planning of the CTR infrastructure needed to support air passenger service in Canada. With respect to passenger services, two entirely different market areas are foreseen for CTR:

(1) high-density short-haul services in urban markets

(2) low-density services in remote regions

While the introduction of CTR technology into the Canadian high-density market represents entry into the most competitive segment of the deregulated air industry, the introduction of CTR passenger service in low-density markets represents the extension of air services to areas where air transportation is currently limited and regulated or nonexistent. The characteristics of CTR services will therefore reflect the specific requirements of these different market contexts.

3.1.1 High-Density Markets

CTR passenger service in high density market areas would co-exist with existing air and ground services, enhancing the options available to the travelling public within the overall transportation system. CTR would both complement and compete with established conventional air services, as well as ground modes such as private cars and intercity bus and rail services. The environment in which this service would take place is characterized by a high density of aircraft movements, densely populated, noise-sensitive areas, the existence of numerous potential hazards to navigation and high cost and limited availability of ground space for vertiport support facilities. To achieve its objectives in this market, CTR will have to provide fast, safe, reliable, convenient and comfortable air service capable of substantially reducing the overall door-to-door time in comparision to other modes of transport.

Fast Service

Since CTR cruise speed performance is limited to 300 - 350 knots (compatible with turboprop but substantially lower than competing jet aircraft), the overall travel time saving will have to be achieved due to means other than reduction of the in-flight time of the en-route section of the itinerary. The following is a general description of the basic CTR system characteristics contributing to the overall reduction of door-to-door travel time.

- vertiport facilities located closer to demand centres than existing CTOL facilities, thus resulting in time savings due to reduction of ground access / egress travel time;
- vertiport passenger terminal facilities substantially smaller than competing conventional airport passenger terminals serving large metropolitan areas, thus generating time savings due to substantially shorter distances between curb facilities and aircraft;
- simplified passenger processing, reflecting the nature of point-to-point O/D dedicated services, thus resulting in time savings within the terminal;
- limited aircraft size, thus minimizing the time required to load and unload the aircraft;
- high frequency of service, thus minimizing waiting time;
- minimum size of airside facilities, thus substantially reducing aircraft ground time during taxi-in and taxi-out operations;
- dedicated flight paths through the Terminal Control Area (designed to take advantage of CTR performance) resulting in shorter and more streamlined routings, thus eliminating delays due to other air traffic waiting for clearance to land or take-off from conventional runways at existing airports;
- direct point-to-point RNAV routes for the en-route portion of inter-city flights, thus resulting in shorter flight distances;
- limited range of 300 - 400 miles (significance of travel time reduction gained from application of above criteria is diminished for routes beyond this length due to limited CTR cruise speed);
- less complicated passenger security procedures, owing to more compact vertiport design and generally less baggage handling.

Safe and Reliable Service

In order to sucessfully compete with fixed wing aircraft in the scheduled passenger service market, CTR vehicles operating in helicopter mode during take-off and landing phases of a flight must overcome the current unfortunate public perception that helicopters are not as safe or reliable as fixed-wing aircraft. In order to achieve appropriate safety levels, CTR vehicles will be required to have certification for Class A engine-out performance; that is, it should be as little affected by the failure of an engine as fixed-wing aircraft. In the case of total loss of propulsion, the vehicle will have to be able to land safely in either wing-borne flight or helicopter autorotation.

In order to offer regular and reliable service, CTR services are expected to operate in IFR conditions and be capable of taking advantage of MLS, GPS and other advanced navigational aids. Considering the environment of large cities, (tall buildings, limited vertiport sites, existing CTOL air routes), CTR will have to be capable of using curved approach and take-off paths and steep approach and departure slopes.

Convenient and Comfortable Service

The typical CTR clientele in the short-haul high-density market consists of business and other people who value their time sufficiently to be prepared to pay a premium for services which will effectively reduce their total door-to-door travel time.

In order to deliver this promise, CTR terminals will have to be located close to traffic demand and offer frequent service throughout working days from early morning until late at night.

The level of comfort on the ground and in the air will have to be superior or equivalent to that offered on competing CTOL services. In terms of aircraft characteristics and amenities this means that the CTR vehicle will have to be pressurized and provide stand-up headroom, and operate from comfortable, passenger-friendly terminals.

3.1.2 Low-Density / Remote Regions

In less competitive commercial environments such as low-density markets and remote sites, CTR services will be characterised by different factors. At these sites the emphasis will tend to be rather on minimizing the costs of ground facilities (capital investment and operational/maintenance expenses) and the provision of minimum-level services to areas which would otherwise be inaccessible by air.

3.2 Typical CTR Flight Mission Profile

3.2.1 Flight Operations

The performance and limitations of specific CTR flight operations have a direct impact on airspace requirements in the vicinity of vertiports and are therefore critical to the integration of CTR technology into urban and other constrained environments. The flight operations and procedures which form part of a typical CTR mission are illustrated in Figure 17, which identifies the various specific phases and segments of flight. Critical phases of a typical CTR flight mission profile can be summarized as follows:

1. lift-off in helicopter mode
2. climb-out and conversion: helicopter to airplane mode
3. transition: airport control zone to en-route airway
   (including climb to long-range cruise altitude)
4. long-range cruise
5. transition: en-route to airport control zone
   (including preliminary descent to conversion phase)
6. descent and conversion: airplane to helicopter
7. vertical landing

Two other versions of representative CTR mission flight profiles, one developed by US V-22 tiltrotor team and other by EUROFAR engineers are presented in Figure 18. In its ultimate configuration a typical flight mission of a fully developed future CTR air transportation system would involve a precision approach to a "target point" in space directly above the vertipad. Navigation aids such as GSP would be utilized to guide the aircraft under IFR to this point. The vehicle would hover (OGE) momentarily in order to positively lock onto the guiding beam of a vertical guidance system (VGS) which would be an expanded-range version of the current MLS or some sort of laser type technology. During take-off procedure, the aircraft would climb vertically to the "target point", at which a normal climb path would be initiated.

The target point corresponding to a critical decision point (CDP) would be at sufficient height above surrounding obstacles to allow safe fly-away procedure with OEI, in the event of engine failure above this point. In the case of engine failure below the CDP, the vehicle would land using OEI procedures.

FIGURE 17
FLIGHT OPERATIONS: TYPICAL CTR FLIGHT MISSION PROFILE

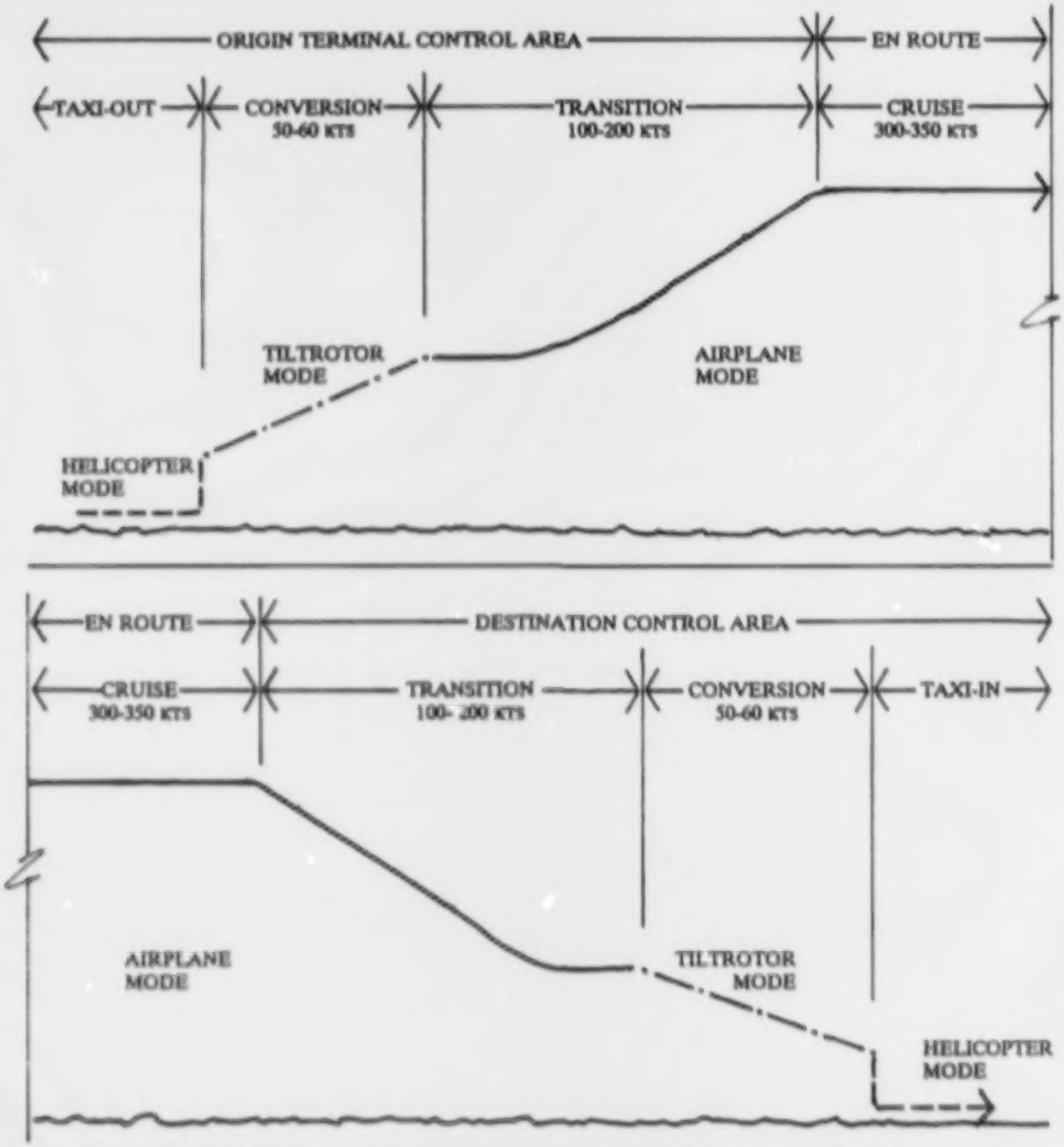
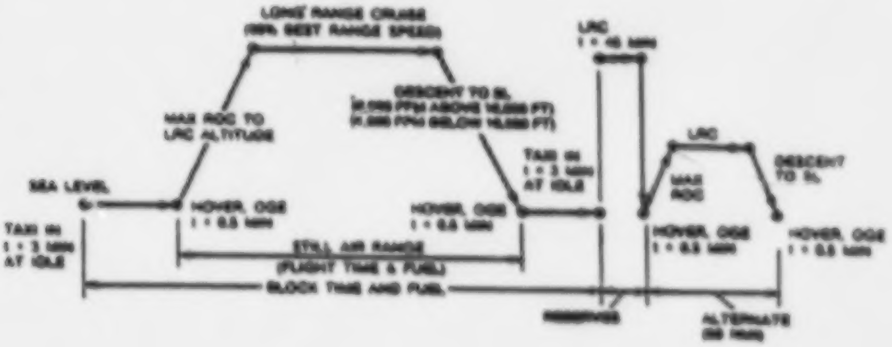
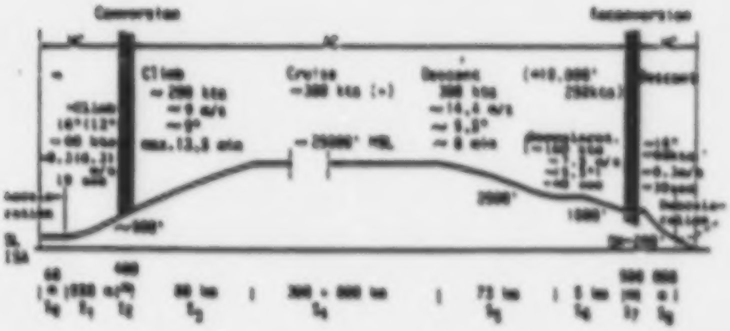

ORIGIN TERMINAL CONTROL AREA
EN ROUTE
TAXI-OUT
CONVERSION
50-60 KTS
TRANSITION
100-200 KTS
CRUISE
300-350 KTS
TILTROTOR MODE
AIRPLANE MODE
HELICOPTER MODE
EN ROUTE
DESTINATION CONTROL AREA
CRUISE
300-350 KTS
TRANSITION
100- 200 KTS
CONVERSION
50-60 KTS
TAXI-IN
AIRPLANE MODE
TILTROTOR MODE
HELICOPTER MODE

FIGURE 18
CTR MISSION FLIGHT PROFILES

US V-22 TEAM


LONG RANGE CRUISE
(99% BEST RANGE SPEED)
MAX ROC TO
LRC ALTITUDE
DESCENT TO SL
SEA LEVEL
HOVER, OGE
t = 0.5 MIN
TAXI out
t = 3 MIN
AT IDLE
STILL AIR RANGE
(FLIGHT TIME & FUEL)
BLOCK TIME AND FUEL
TAXI in
t = 3 MIN
AT IDLE
LRC
LRC
MAX
ROC
DESCENT
TO SL
HOVER, OGE
t = 0.5 MIN
HOVER, OGE
t = 0.5 MIN
RESERVES
ALTERNATE

EUROFAR TEAM


Conversion
Reconversion
Climb
~250 kts
~9 m/s
~9°
max.13,5 min
Cruise
~300 kts (+)
~25000' MSL
Descent
300 kts
~14,4 m/s
~5,5°
~8 min
2500'
1000'
SL
ISA
80 km
300 ÷ 800 km
73 km
5 km

3.2.2 Vertical Take-Off Procedures

The vertical take-off in visual meteorological conditions (VMC) should pose no problems. The required checks of engine/prop, clutch, cross shaft and overspeed governing are conducted at relatively high power, while still on the ground. Power is then added and the aircraft rapidly becomes airborne in ground effect (IGE). As it rises in ground effect towards an equilibrium height, the pilot continues to add power to maintain a constant dh/dt (vertical speed). Control power of the CTR will be high giving precise control and positioning capability. The ability to precisely position the aircraft in 3-D space using visual clues decreases with height rather rapidly so that at heights within the 60 - 120 ft range, either a cone of accuracy must be established or additional cockpit instruments must be used.

For the purposes of vertical take-off under instrument meteorological conditions (IMC), Electronic Flight Instrument Systems (EFIS) are currently available which will reduce and greatly simplify the instrumentation task - such that the central Electronic Attitude Direction Indicator (EADI) display will be capable of being switched from vertical to STOL/Conventional modes. This instrumentation will be mandatory for the all-weather requirements of the operation. Thus one can envisage an instrument, like a 2-axis instrument landing system (ILS) localizer, with a 90 degree glide slope.

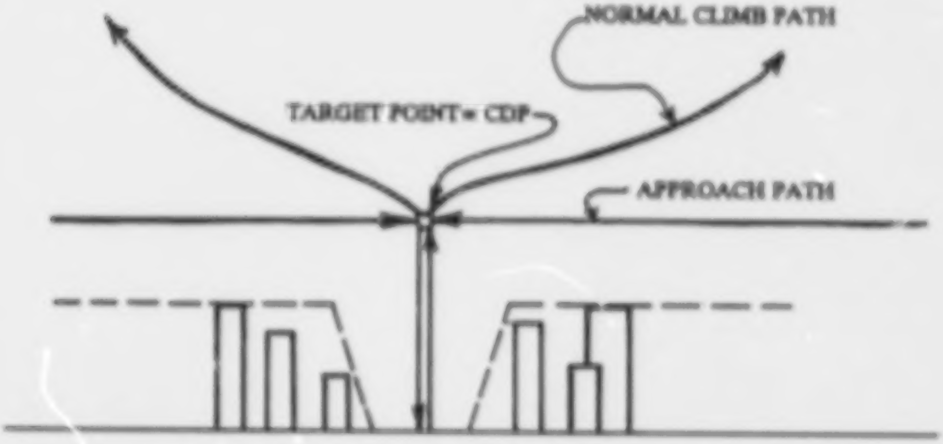
3.2.3 Vertical Landing Procedures

The CTR vertical landing will commence from a STOL descending approach (say 40 knots CAS) to a geographic point vertically above the landing site. As the aircraft approaches this point in space, the pilot will decelerate by tilting the thrust vector up until the ground speed is zero. The final approach will be made into the wind.

As the ground speed drops to zero, the pilot will slightly reduce the thrust and establish a rate of descent which will be maintained until the aircraft starts to react to ground effect. At that point power (thrust) is manipulated to reduce the rate of descent until touch-down - at approximately 1-3 ft/sec.

In high or gusty wind conditions longitudinal position will be maintained with fore/aft thrust vector variation, pitch attitude and tilt; lateral corrections will be applied through thrust vector variation laterally by banking the aircraft.

FIGURE 19
VERTICAL CTR TAKE-OFF / LANDING PROCEDURES


NORMAL CLIMB PATH
TARGET POINT = CDP
APPROACH PATH

4. AIR NAVIGATION SYSTEM

Broadly defined, the air navigation system represents the infrastructure required to manage an aircraft from the time that it leaves a parking area at the point of departure until the time that it terminates its flight at the destination. With respect to CTR operation, the air navigation system requirements are a function of the way in which the vehicle will operate in the airspace environment under different missions.

The introduction of CTR as an air transportation mode will require the establishment of distinct elements of aeronautical and airport infrastructure to support the new services and derive maximum benefit from the enhanced operational characteristics of the vehicle. In general, CTR services and vertiports will have to be planned in relation to the existing and planned aeronautical infrastructure and air navigation system, including airspace, equipment (navigation aids, communication, surveillance and meteorological equipment) and air traffic services and control. In Canada, the federal regulatory agency, Transport Canada, is responsible for managing airspace and for developing and operating the public air navigation system.

The introduction of CTR technology is expected to have a positive impact on the overall capacity of the existing air navigation system, especially in the critical terminal area. This expectation is based on the fact that, due to its enhanced manoeuverability, CTR aircraft will be capable of utilizing airspace not suitable for fixed-wing craft. To quote from a recent U.S. report, **The Design Challenges of Applying Tiltrotor to the Civil Mission,** (Ward Associates, August 1989):

> *The tiltrotor's promise lies in the opportunity to provide relief to the growing problem of transportation gridlock and airport capacity saturation. However, this requires that the tiltrotor be designed to operate safely and routinely into busy airports on a non-interference basis. While it appears that the enabling technology is available, this will be a major challenge in aviation system design.*

Experts in the U.S. have estimated that "full development and certification for operational use of tiltrotor technology could occur in the 2000-2005 time frame". Most of the data available today in the area of air navigation requirements for the tiltrotor exists as a result of work completed and in progress in the U.S and, to a lesser extent, in Europe. The present report draws from this data but the observations and conclusions are, as much as is possible, recapitulated in a Canadian context. This section of the report examines the individual components of the Canadian air navigation system. Its aim is to identify those areas which will be impacted by the introduction of CTR in Canada and to explore the relevant planning criteria and parameters.

4.1 Airspace Architecture

The introduction of CTR services will require the incorporation of provisions to accommodate and take advantage of the operational characteristics of CTR aircraft in the "architecture" of Canadian airspace. In general, the airspace system design is intended to promote safety and efficiency by eliminating bottlenecks and congestion and simplifying air traffic control, taking into account the flight characteristics of different categories of aircraft; densities of traffic; location, category and orientation of runways; navigation and communication aids; air traffic services; and other factors.

The introduction of CTR will require the establishment of designated air routes within air terminal areas in order to ensure independent operations and thus to maximize the potential benefits of the new technology in terms of improving safety and capacity in congested terminal airspace environments. CTR service will not require the establishment of dedicated airways outside terminal control zones. In-flight performance and characteristics are comparable to turboprop aircraft; CTR, therefore, can share currently established CTOL air routes.

With respect to airspace in the immediate environment around proposed vertiports, CTR operations will require the establishment of special aeronautical zoning to protect approach and departure surfaces, as is the case with conventional airports and CTOL operations. The extent of CTR protected surfaces, however, will be considerably less intrusive and should, therefore, permit greater flexibility in the siting of vertiports close to the potential centres of demand, e.g. near urban downtown areas. Operational criteria for the precise definition of these surfaces, however, are still in the developmental stage, as testing of the aircraft and its critical performance parameters continues.

Provisions for accommodation of tiltrotor operations will involve the following components of the overall airspace system architecture:

- En-Route Airspace
- Terminal Control Area
- Flight Paths
- Missed Approaches
- Holding Areas
- Vertiport Protected Airspace

4.1.1 En-Route Airspace

Tiltrotor aircraft in the en-route phase of flight will likely be indistinguishable from any other conventional turbo-prop aircraft. Designed and equipped to operate within the same envelope of operationally suitable altitudes used by its fixed-wing counterparts, the tiltrotor will be capable of navigating within the current en-route airspace system. With a nominal mission radius of 300 nautical miles and capable of speeds in the neighbourhood of 300-350 knots, it will display similar performance characteristics to other currently operating short-haul aircraft, and will use similar avionics. Nothing in the known design of this aircraft, or its anticipated role, indicates that major modifications to the structure of airways and air routes will be required initially to accommodate tiltrotors in Canada.

In order to facilitate and derive maximum benefit from the introduction of CTR services, however, it may be advisable to establish distinct ATS routes in certain environments, in order to take advantage of the vehicle's operational flexibility. An ATS route is a specified route designed for channelling the flow of air traffic as necessary for the provision of air traffic services. The establishment of such routes offers an effective method of airspace usage and a means of achieving an effective traffic flow between points of origin and destination. As in the U.S. and Europe, a dedicated route structure for the tiltrotor might become desirable at some time in Canada, in order to increase capacity in the congested airspace around airports such as Toronto, Montreal and Vancouver and to provide more direct point-to-point routes through the en-route airspace.

A detailed study into this possibility might well suggest route structures similar to those that were in effect between 1974 and 1976 during the STOL demonstration project undertaken by the Transportation Development Centre of Transport Canada and operated by AirTransit (a commuter airline created for that purpose by Air Canada). Among its many findings, the main report[1] on this project noted that aircraft were able to operate successfully "through a busy airspace with the use of area navigation (RNAV)".

RNAV, in its various forms, is now being refined and used in many parts of the world. In the future, advanced electronic equipment and improved, less restrictive airspace criteria might result in dedicated tiltrotor routes requiring a lesser extent of protected airspace, thereby increasing the overall flow capacity of the en-route air navigation system. Dedicated ATS routes might also be used to facilitate traffic between stand-alone, near-urban vertiports (thereby making the service more attractive to the user) or to direct the aircraft away from densely populated, noise sensitive urban areas. The longer range perspective could conceive of one-way routes for different directions being designed to eliminate conflicts between tiltrotors, themselves competing for the finite airspace available in the vicinity of large, urban communities.

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[1] **STOL Demonstration Montreal-Ottawa 1974-1976 - Main Report.** September 1978, Transport Canada. TP 1687.

4.1.2 Terminal Control Area

The terminal control area of the airspace system is generally centred on an airport or group of airports and accommodates the following phases of flight:

a. the transition between the en-route phase and final approach and landing at an aerodrome;
b. the transition between take-off and en-route phases of the flight.

The integration of CTR operations into the planning of terminal control areas around vertiports will involve consideration of a number of factors, including:

- the likelihood / frequency of aircraft conducting VFR flights in the area;
- the presence of IFR traffic;
- the potential of conflict between the various users;
- the location and orientation of airport, heliport and vertiport landing and take-off facilities;
- the land-based communication and navigation equipment in the area and the signal coverage of each;
- the flight performance characteristics of tiltrotor aircraft;
- the possible consequences of an accident to people and property on the ground;
- municipal and provincial legislaton, including noise abatement regulations.

To avoid the possibility of conflict between aircraft, it might be feasible to simply "sterilize" the airspace immediately surrounding a vertiport by banning VFR flight within this area. This option might in fact be difficult to accomplish. Many commercial operations, from traffic reporters to police, security and medical emergency flights, helicopter hauling and lifting operations, etc. to the odd banner-tow aircraft, depend for their existence - as will the tiltrotor - on the relatively free use of the airspace directly over large urban centres.

Today, these various users operate by-and-large under VFR, the only real restrictions being special routes for some routine operators (such as traffic report aircraft) or the occasional special authority for aircraft performing non-routine activities that present some risk to those on the ground. Various flight restrictions are made known to other users mainly by publications such as NOTAMS and Information Letters. The presence of large, busy airports in the vicinity may complicate the siting and design of terminal airspace for vertiports. It will be necessary to study in detail, and perhaps modify, certain IFR patterns.

4.1.3 CTR Flight Paths (including missed approaches)

The introduction of CTR will require the establishment of designated air routes within air terminal areas in order to ensure independent operations and thus to maximize the potential benefits of the new technology in terms of improving safety and capacity in congested terminal airspace environments. Such routes in the vicinity of vertiports could serve a number of purposes, namely;

- They could be designed to minimize the possibility of conflict between tiltrotors using the same vertiport or different vertiports in the same general vicinity. Should these vehicles operate under VFR, a special route pattern might be considered that would permit an aircraft to approach the vertiport safely while another is departing.

- One of the strongest features of the tiltrotor concept is the capability of the vehicle to use an autonomous vertiport. While this may create problems, particularily for the siting of these installations, any significant number of tiltrotors using a vertiport is likely to result in an off-loading of fixed-wing commuter demand at nearby, conventional airports. To maximize the benefits of this, routes could be developed that would direct tiltrotors around, and therefore clear of, the traffic patterns used for fixed-wing aircraft in the terminal area thus increasing airspace capacity and perhaps decreasing controller workload.

- Tracks might be developed that would permit other aircraft (either fixed-wing or other rotorcraft) to avoid the final approach areas or the departure and missed approach paths of tiltrotors.

- Airspace over densely populated or noise sensitive sectors (hospitals, schools, housing, etc) of a metropolitan area could be protected by the use of special routes for tiltrotors taking advantage of their high degree of manoeuverability.

The design of these designated CTR flight paths would reflect the ability of the vehicle to perform steeper approaches and fly at slower speeds than fixed-wing aircraft while generating less noise than helicopters in horizontal flight.

4.1.4 Holding Areas

For many years, the air traffic control system has used the aircraft hold procedure to increase airspace capacity, particularly around busy airports. The protected airspace for a fixed-wing aircraft hold area is relatively large, even for an aircraft holding at the lowest possible altitude. Plotted over a metropolitan area, these protected areas constitute a constraint on IFR movement in the sector since an air traffic controller is not permitted to authorize a second IFR aircraft to enter or pass through the protected airspace of the aircraft executing a holding manoeuvre.

In recent years, the emphasis on fuel economy has resulted in attempts to reduce or eliminate holding in the air by the use of "flow control", i.e. ensuring that aircraft can be handled expeditiously by ATC before they are allowed to leave the ground. Despite the best efforts of improved ATS automation, however, some airborne holding is and will remain necessary, in order to ensure adequate air safety. The tiltrotor, with its unique operating characteristics, will give much greater flexibility to airspace planners with respect to the requirements for safe holding patterns:

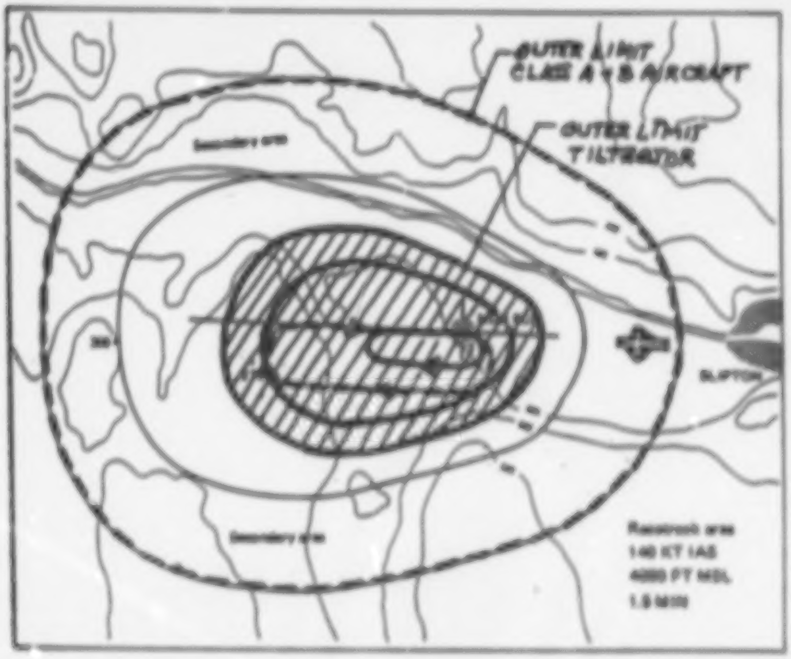
- smaller area required due to the slow flight, tight turn and hover capabilities of the vehicle;
- enhanced flow control characteristics due to the ability of the vehicle to fly safely at a wide range of forward speeds, from stationary to 350 knots;
- possibility of using existing holding areas for other airports;
- possibility of using minimal ground facilities in the case of emergency landings.

Figure 20 provides a graphic comparison of the space required for CTR versus fixed-wing holding areas.

4.1.5 Vertiport Protected Airspace

With respect to airspace in the immediate environment around proposed vertiports, CTR operations will require the establishment of special aeronautical zoning to protect approach and departure surfaces, as is the case with conventional airports and CTOL operations. The extent of CTR protected surfaces, however, will be considerably less intrusive and should, therefore, permit greater flexibility in the siting of vertiports close to the potential centres of demand, e.g. near urban downtown areas. Operational criteria for the precise definition of

FIGURE 20
COMPARISON OF CTR AND FIXED-WING HOLDING AREAS



these surfaces, however, are still in the developmental stage, as testing of the aircraft and its critical performance parameters continues. The ultimate arrangement and geometry of these surfaces is related to the certifiable approach and take-off slopes, including the vertical let-down height allowance.

It is expected that CTR aircraft will eventually be able to use steeper approach glide paths than currently used by CTOL or even steeper than those achievable by current rotorcraft. This expectation is based on the particular ability of the CTR to independently control lift vector and body angles through tilting of the nacelle (V22), proprotor and shaft (EUROFAR) or wing (Ishida). At present, a number of research activities being carried out in the U.S. are directed to evaluating the extent of the ability of the CTR to use steep approach angles as high as 25 degrees. It is further expected that precision approaches to a point-in-space followed by vertical let-down will eventually be achievable. This particular capability will provide maximum flexibility in the location of vertiport facilities in urban environments. In effect, the ability to site vertiports in such areas will be a key factor in the overall usefullness and commercial success of CTR in the public transport domain.

In Europe, the EUROFAR preliminary basic studies related to typical CTR profiles and approaches have indicated that a 15 degree glide path slope should be feasible using existing MLS technology. Planners consider integration of a vertical precision guidance system allowing safe, near zero/zero instrument VTOL operation as the ultimate solution for successful CTR operation. At the present time, there are no accepted standards which would define imaginary planes delimiting protected airspace for vertiports. The most advanced work which exists to-date on the subject is that of the FAA/Industry Vertiport Working Group in the form of the **FAA Draft Advisory Circular No. 150/53xx-xx - Vertiport Design**. This document specifies required the protected airspace for a vertiport by defining three basic planes/surfaces identified as the *primary surface*, the *approach/departure surface* and the *transitional surface*. A minimum of two approach and departure paths must be provided if the vertiport is intended to accommodate airline type operations.

The *Primary Surface* is a horizontal plane the size and shape of the Final Approach and Take-off Area (FATO) at the elevation of Touchdown Lift-off Surface (TLOF) (see description of FATO and TLOF in Chapter 5).

The *Approach/Departure Surfaces* are inclined trapezoidally shaped planes beginning at the edge of the primary surface and sloped upward and outward in the direction of each approach or departure. Two different slopes and sizes of these surfaces are defined according to the type of flight operation. For visual and non-precision operations they are referred to as Approach/Departure Surfaces. For IFR operations, they are defined as Precision Instrument Approach Object Identification Surfaces.

The *Transitional Surfaces* are sloping planes rising from the edge of the Primary Surface and the Approach /Departure Surface. As with the latter, two different shapes and slopes are defined depending on whether visual/non-precision or IFR operations are involved. For the latter, they are referred to as Transitional Object Identification Surfaces.

Figure 21 and Table 7 illustrate the basic geometric arrangement and sizing of the above-described surfaces as presented in the draft version of the **FAA Advisory Circular** dated 1/9/90.

FAA standards and recommendations presented in this Circular do not regulate or limit the operations of any current or future rotorcraft or tiltrotor aircraft. They represent an initial attempt by the FAA to establish criteria which would permit certification of vertiports to be used in eventual V22 demonstration programmes. Due to the fact that hard data on the civil version of V22 are nonexistent, it is understandable that these proposed standards are quite conservative and are more or less derived from experience with demonstrated helicopter performance. The Advisory Circular allows provision for the modification of these standards on the basis of demonstrated equipment capability and acceptable levels of safety, economy and reliability. Circumstances may eventually justify the restrictive certification of specific vertiports that limit usage to a specific type of high-performance tiltrotor aircraft. In these cases, steeper approach/departure slopes would result in a reduction of protected airspace requirements.

An ultimate long-range scenario would assume vertical landing and take-off operations at downtown vertiports. The vertical phase of the flight would be initiated or terminated at the point centered above the FATO area, well above all surrounding structures and obstacles. This arrangement would permit safe approaches and departures from any direction, thus allowing for safe, economical operations by rotation of the aircraft into the prevailing winds. In such an operational environment, the requirement for protected airspace would be minimized and delimited by geometric shapes such as those illustrated in Figure 22. This type of operation is expected to be feasible with future generations of rotorcraft technology and assumes the availability of advanced navigation aids capable of vertical guidance.

Appendix 3 discusses the different options for the angle of the Approach / Departure Surface which are being considered at this time by aviation planners. These options relate to assumptions regarding the ability of the CTR vehicle to perform safe landing and take-off operations under IFR conditions at different vertical angles. The question is crucial since it directly affects the land and airspace requirements of vertiports and, thus, the possibility of establishing sites in some constrained locations.

4.2 Navigation and Telecommunications

4.2.1 Navigation Aids

Air navigation aids are of prime concern to any air service intended for all-weather operations. For the tiltrotor, a system of navigation aids will be required to ensure safe and efficient operation of the vehicle, especially in the increasingly crowded environment between and around the major centres of population. Most cities in Canada today are already served by air navigation aids installed to provide adequate signal coverage for the various airports in the area. Airspace planners will need to study and flight-test these aids in order to ensure that they also provide adequate coverage to permit safe navigation of tiltrotor aircraft between the enroute airway structure and the area in the vicinity of the vertiports within which an approach and landing or a departure will be done.

FIGURE 21
VERTIPORT PROTECTED AIRSPACE - IMAGINARY PLANES

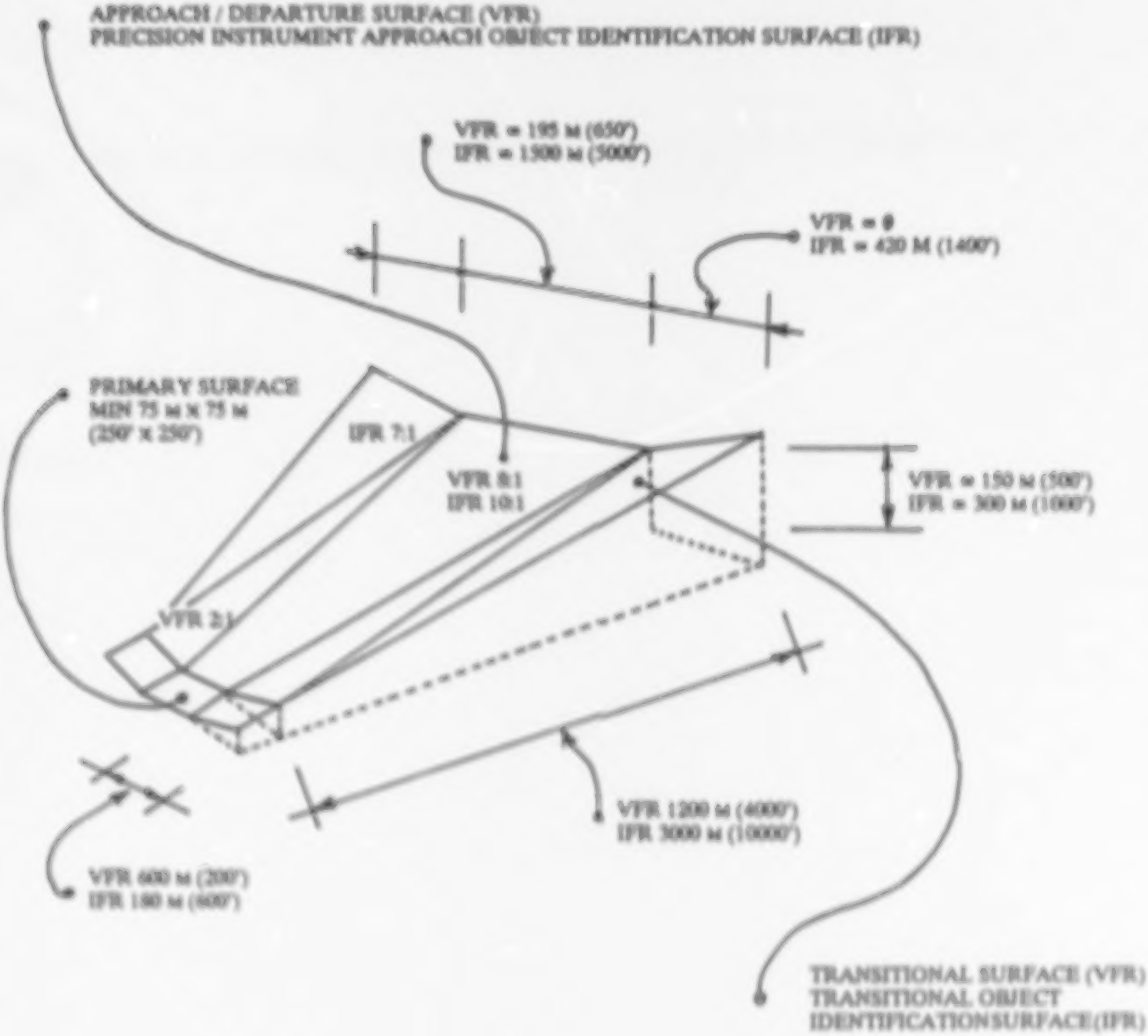

APPROACH / DEPARTURE SURFACE (VFR)
PRECISION INSTRUMENT APPROACH OBJECT IDENTIFICATION SURFACE (IFR)
VFR = 195 M (650')
IFR = 1500 M (5000')
VFR = 0
IFR = 420 M (1400')
PRIMARY SURFACE
MIN 75 M X 75 M
(250' X 250')
IFR 7:1
VFR 8:1
IFR 10:1
VFR = 150 M (500')
IFR = 300 M (1000')
VFR 2:1
VFR 1200 M (4000')
IFR 3000 M (10000')
VFR 600 M (200')
IFR 180 M (600')
TRANSITIONAL SURFACE (VFR)
TRANSITIONAL OBJECT
IDENTIFICATIONSURFACE(IFR)

TABLE 7
VFR AND IFR PROTECTED CTR AIRSPACE REQUIREMENTS

Protected Airspace Imaginary Planes		Operations	
		VFR	IFR
Primary Surface			
shape		FATO	FATO
size		FATO (2)	FATO (2)
elevation		TLOF	TLOF
Approach/Departure Surface			
shape		trapezoid	trapezoid
width	- lower edge	FATO	FATO
	- upper edge	195 m (650 ft)	1500 m (5000 ft)
length (3)		1200 m (4000 ft)	3000 m (10000 ft)
elevation	- lower edge	TLOF	TLOF
	- upper edge	150 m (500 ft)	300 m (1000 ft)
slope		8 : 1	10 : 1
Transitional Surface			
shape		triangular	trapezoid
width (3)	- lower edge	60 m (200 ft)	180 m (600 ft)
	- upper edge	0	420 m (1400 ft)
length (3)		1200 m (4000 ft)	3000 m (10000 ft)
slope		2 : 1	7 : 1

(1) visual and non-precision
(2) minimum 75 m x 75 m (250 ft x 250 ft)
(3) horizontal dimension

FIGURE 22
VERTIPORT PROTECTED AIRSPACE - VERTICAL LANDING AND TAKE-OFF

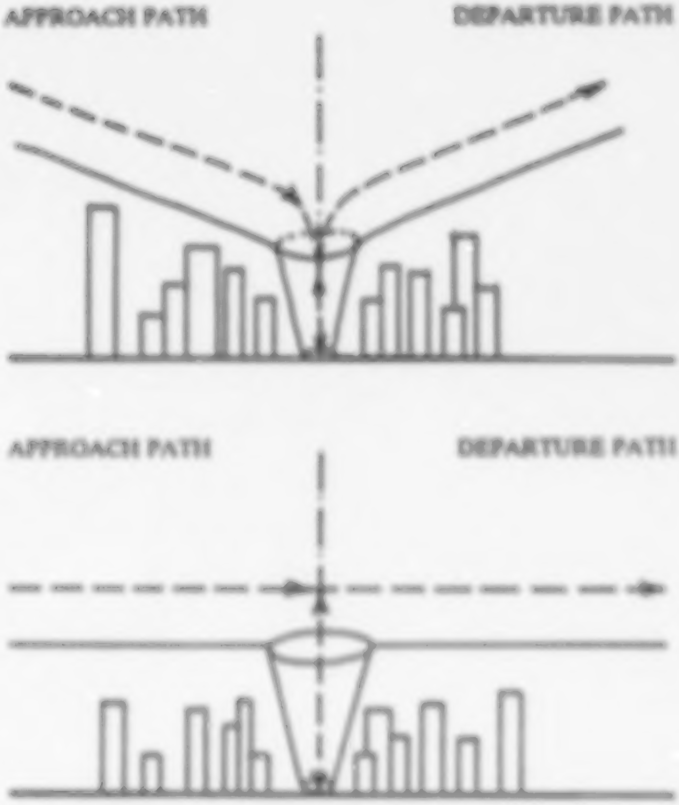
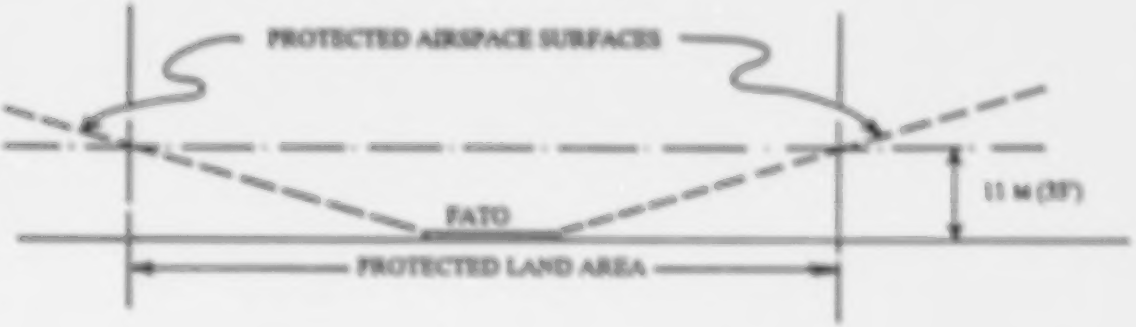

APPROACH PATH
DEPARTURE PATH
APPROACH PATH
DEPARTURE PATH

FIGURE 23
VERTIPORT PROTECTED LAND VS. PROTECTED AIRSPACE



It may be necessary to install additional navigation aids at some vertiport sites where the service provided by existing aids, which operate for the most part at frequencies giving essentially line-of-sight coverage, is unsatisfactory due to propagation phenomena, such as signal blocking or multipath reception. The mode of operation of this new technology will require vertiports to be equipped with an all-weather instrument landing system that permits vertical or near-vertical take-offs and landings. Research is presently underway to modify the microwave landing system to permit this type of operation. It would appear that such modifications are feasible and could provide the CTR with the required type of navigation aid for vertical take-off and landing manoeuvres.

Visual Aids

Since visual reference is essential for vertiport airside facilities from a safety point of view during the final stages of aircraft approach and landing in conditions of low visibility, the installation of MLS or other non-visual navigational aids does not obviate the need for visual aids at the vertiport. A number of visual navigation aids compatible with those required for helicopters will be required at vertiports:

- Vertiport Beacon
- Approach Lighting System
- Visual Glide Slope Indicator
- Wind Indicator
- Airfield Lighting

Following are the parameters regarding the location of the above aids according to the above-mentioned **FAA Advisory Circular**.

Vertiport Beacon

The beacon should be located on, or immediately adjacent to the vertiport in such a way that it will not penetrate any of the protected surfaces and will not interfere with the vision of the pilot or vertiport controller.

Approach Lighting System

The geometry of the vertiport Approach Lighting System required for IFR operations is shown in Figure 24.

Visual Glide Slope Indicator

Three different systems could be employed at vertiports for the purpose of providing reference for visual approaches: Visual Approach Slope Indicator (VASI), Precision Approach Path In-dicator (PAPI) or Pulse Light Approach Slope Indicator (PLASI).

Wind Indicator

A Wind Indicator is recommended for both VFR and IFR operations. It should be located in such a way that it does not penetrate any of the protected surfaces and should be visible to pilots taxiing for take-off and approaching to land. The wind cone must be lighted for night operations.

Airfield Lighting

Vertiport lighting will use standard aviation lighting fixtures, to provide visual references for aircraft manoeuvering by defining the edges and centerlines of the following elements of the vertiport aerodrome:

FATO
TLOF
Taxiways
Aprons

Microwave Landing System (MLS)

The current International Standard MLS, as described in the ICAO Annex 10, Volume I, was envisaged for straight-in, segmented or curved approaches to a single landing runway, at descent angles used by CTOL, STOL and conventional VTOL aircraft (see Figure 25). It provides lateral signal guidance within a range of plus or minus 40 degrees from the runway centreline, and from the ground to an angle of 15 degrees from the horizontal, measured from the azimuth antenna, with some variation for special coverage areas. An accompanying ICAO Recommended Practice (desirable, but not essential) states that vertical coverage should extend from the ground to an angle of 30 degrees from the horizontal, and most manufacturers have taken this additional vertical coverage into consideration in their concept of the vertical element of the system.

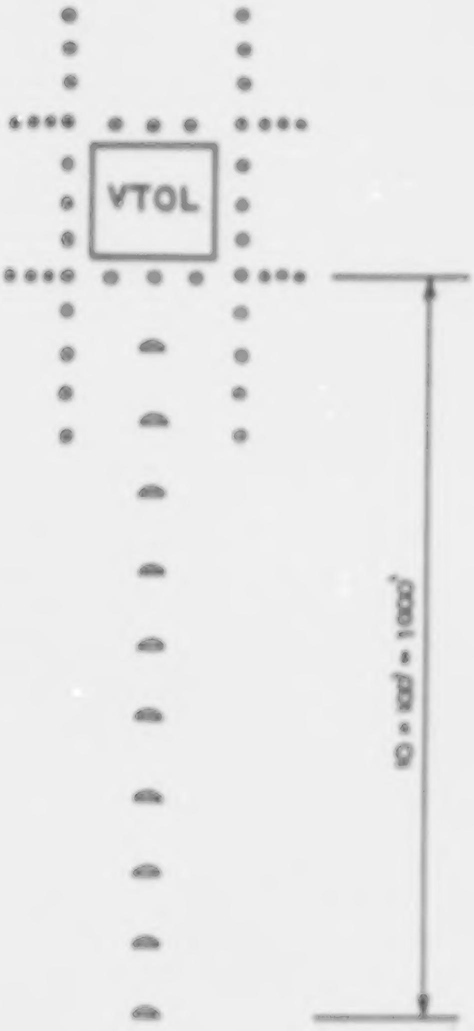
The MLS is a time-referenced system, and an extension of coverage in either dimension involves additional computation and programming. The practicality of such extensions would therefore have to be measured against the cost of other more specialized, and therefore potentially more economical add-on methods of providing broader azimuth and vertical coverage. Full (360 degree) azimuth coverage is ideal for tiltrotor application, but for most practical applications prevailing winds or topography will limit approach directions, so that one or two appropriately sited MLS installations would satisfy operational requirements. Vertical guidance to 90 degrees from the horizontal would probably require an add-on ground system, to be integrated with the airborne system.

The FAA Advisory Circular accepts MLS as the most practical system for a precision instrument approach to a vertiport at the present time. This is a system which will be used in the planned V22 demonstration programme. The following diagram (Figure 26) illustrates possible placement of MLS installations at a typical vertiport. For specific sites, the establishment of these locations will have to take into consideration the environmental constraints of the vertiport surroundings. It should be noted that the eventual application of relatively steep MLS glide slope angles for direct approaches to urban vertiports may be limited by the presence of tall structures in the vicinity of the landing area. Cases of this type may require the design of let-downs aimed at an approach area some distance from the vertiport that will permit the pilot to reach the decision height (DH) clear of obstructions, then proceed to the vertiport.

4.2.2 Telecommunications Equipment

It is not expected that CTR air services will require any additional telecommunications systems above and beyond those used by other forms of aviation. Mention has already been made of the coming use of mobile-satellite data interchange capability, and its application to

FIGURE 24
VERTIPORT INSTRUMENT APPROACH LIGHTING SYSTEM


VTOL
10 × 100' = 1000'

air traffic control problems as an antidote to air traffic congestion problems that appear beyond the capabilities of manual air traffic control. The future CNS concept provides for emergency mobile-satellite voice capability, but it is expected to be limited in its application, primarily because of satellite power budget considerations, the inconvenience and possible confusion caused by propagation delays, and other less important factors. There is some evidence that a high quality data interchange service, with convenient input-output terminals both in the air and on the ground, will virtually eliminate the requirement for mobile voice communications, except for very rare emergency use.

The future CNS concept provides for terrestrial VHF voice communications to serve busy air traffic control environments, as it appears that no other method can serve this function with equal efficiency. Unfortunately, this will place an additional strain on the demand for frequencies, and VHF bands are already fully saturated in many parts of the world. The VHF frequency congestion problem is apt to require further channel splitting to 12.5 kHz separation, and may eventually place negative pressure on the use of VHF for air-ground data interchange. These developments are likely to appear at the same time, or shortly after, the expected introduction of tiltrotor operations.

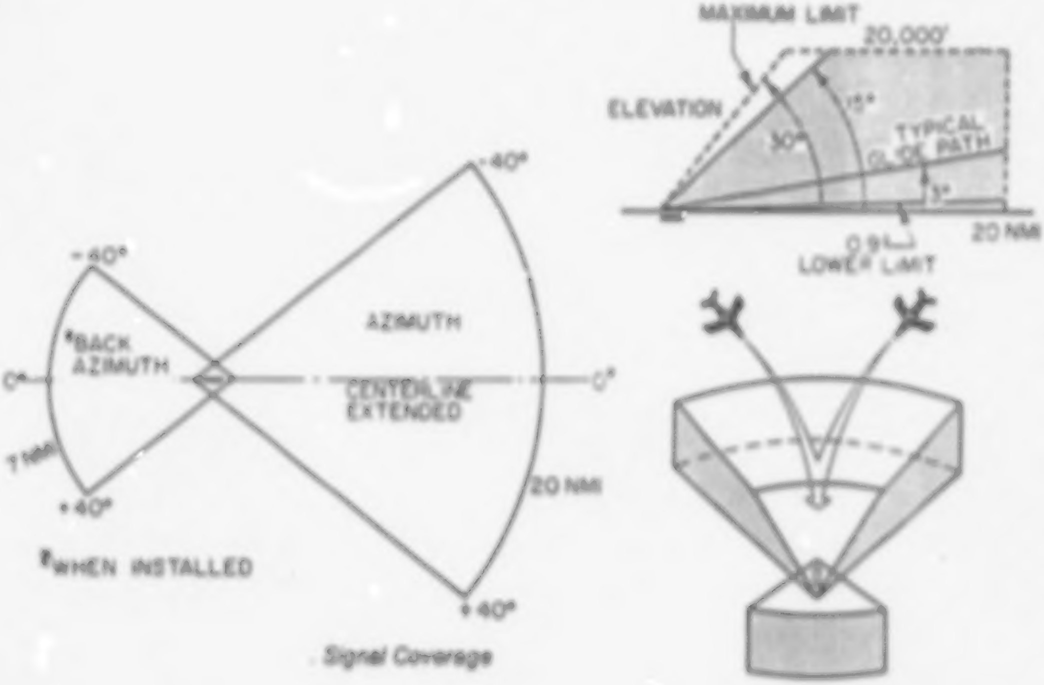
Experience will eventually indicate any special problems associated with tiltrotor communications when operating into densely populated areas, but it would appear that any conceivable problem could be handled by the appropriate application of existing communications technology. It appears that by the time tiltrotor operations are likely to be feasible, adequate airborne satellite antennas will be readily available, thus eliminating one of the more serious limitations of practical satellite relay service at the present. Until recently, the system's antennas have been too large to install on the aircraft. Smaller antennas, such as the Canadian Marconi Mascot, have now been developed for use on-board the aircraft.

4.2.3 Advanced CNS Systems

For the long-term economic feasibility of the tiltrotor, it is assumed that work will proceed toward the design, development and certification of a true VTOL terminal precision operating system that will provide full (360 degree) azimuth and true vertical (90 degree) all-weather approach and departure guidance. Examples of possible future systems that may be used to accomplish this goal are:

- satellite-based navigation technology;
- Night Vision Pilotage System, using FLIR imaging
- laser rangefinder;
- IR and TV systems with multiple fields of view;

FIGURE 25
STANDARD MICROWAVE LANDING SYSTEM LIMITATIONS

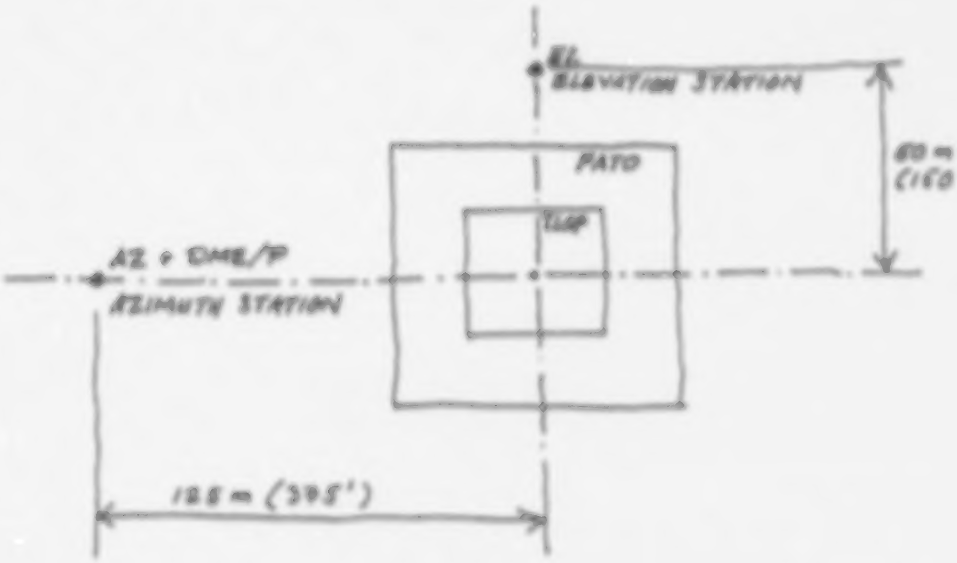

MAXIMUM LIMIT
20,000'
ELEVATION
15°
30°
TYPICAL GLIDE PATH
3°
0.9
LOWER LIMIT
20 NM
-40°
+40°
AZIMUTH
*BACK AZIMUTH
0°
CENTERLINE EXTENDED
0°
7 NM
+40°
20 NM
*WHEN INSTALLED
+40°

Signal Coverage

- automatic approach, hover and climb-out;
- pre-programmed input for navigation and communication;
- Advanced Cockpit Evaluator, etc.

Tiltrotor aircraft will make extensive use of automation, as their development coincides with universal developments in this field. They will also be required to have SSR Mode S capability, as parts of their operational mission will take place outside primary radar coverage, and in Canada, at least, en-route radar coverage will be by SSR, making its installation in tiltrotor aircraft a necessity for efficient operation. Additionally, in the USA at least, it may be required to participate in collision avoidance activity known as Tactical Collision Avoidance System (TCAS), of which there are two versions, TCAS I and TCAS II, the latter for more sophisticated operations.

FIGURE 26
PREFERRED LOCATION OF MLS AT VERTIPORT



Future Air Navigation System (FANS)

An overall concept for a future Communications, Navigation and Surveillance (CNS) air navigation system was developed recently by the Future Air Navigation System (FANS) Committee of ICAO, and activity aimed at the implementation of this concept is continuing within ICAO. In the strictest sense, this concept applies to international civil aviation operations only. However, since all aircraft share common airspace at some time, or at least have the capability of doing so, there must be co-ordination of air navigation systems, and the capability of smooth and unobtrusive transition at system interfaces. For this reason, the international FANS Committee recommendations will eventually form the basis for the design of national tiltrotor operations.

The future CNS concept of the FANS Committee is based on extensive use of satellite technology, but also includes specific terrestrial systems, such as VHF mobile voice communications and SSR Mode S in areas of dense air traffic activity, such as in busy terminal areas. Mobile satellite communications are expected to provide, for the first time, an extensive data exchange capability between aircraft and the ground, on a universal coverage basis. For some time now, the latest versions of civil aircraft have incoroporated in their avionics a considerable capability for automation, and this capability has been used to improve operational efficiency, usually via VHF data links operating on operational control frequencies.

GPS and GLONASS

Satellite data links offer an opportunity to extend coverage on a universal basis, and to extend automation to air traffic services and other safety functions. The required automation of air traffic control and other functions is proceeding at a rapid rate and is considered essential to the future needs of the air navigation system. The Global Positioning System (GPS) being implemented by the United States, and the Global Navigation Satellite System (GLONASS) being implemented by the former USSR, are currently providing limited navigation service to properly equipped terrestrial vehicles, and are expected to provide full satellite navigation service in 4-5 years time.

While the two systems differ in operational details, activity is proceeding to develop a receiver capable of using either or both systems. Various signal augmentation and monitoring programmes have been proposed to improve the usefulness of the two systems to civil aviation users. As progress towards full automation of tiltrotor operations is made, increased emphasis on reliability, availability and integrity of satellite positioning systems in the very difficult built-up urban environment will also be required. It is expected that the large number of orbiting satellites providing the service will ensure reliable coverage in the most critical urban environment, although some special investigation of multipath propagation effects may be required in some cases.

4.3 Air Traffic Services

Assuming that CTR vehicles will eventually be certified to operate in IMC, measures will have to be taken to ensure that appropriate air traffic control services are available. This implies the designation of controlled airspace related to vertiports, requiring that certain specific conditions be met regarding navigation and communications signal coverage.

4.3.1 Terminal Control Area

Within the Terminal Control Area, ATC should provide for independent operations between CTR and CTOL, in order to take advantage of the ability of the aircraft to take-off and land vertically, climb rapidly at steep angles, move slowly and maintain a stationary airborne position. This separation will have a positive effect both on the overall terminal airspace capacity and on flight safety. There will be several choices open to the air traffic control planners tasked to identify controlled airspace requirements around a vertiport (or several vertiports). One option is to establish airport control for the vertiport in question. Simply defined, airport control is the control of all aircraft - IFR and VFR - within a certain distance of the airport (normally within a radius of several miles), from the ground to a specific altitude above the ground. Generally, airport control service is provided at those locations where the potential of conflict between aircraft threatens flight safety, usually at airports with a high level of IFR all-weather operations in the presence of VFR operations.

In many areas near airports heavily used by IFR aircraft, VFR operations are not permitted, and such areas are likely to increase in number as air traffic volume increases. This may be particularly true for urban vertiports in future, especially when one considers the consequences of an accident to the communities below. If VFR movements in the vicinity of vertiports are restricted in the future, tiltrotors might be controlled by an instrument (IFR) controller using radar terminal control techniques (ie; vectors to the final approach course, or even standard straight-in approaches on dedicated corridors) and established holding patterns, to guarantee safety between the various IFR users. In this scenario, controlled airspace might simply involve the enlargement of the terminal control areas that exist around all airports with terminal control services. The control of IFR flights in the proximity of large Canadian urban centres is today performed exclusively using radar control techniques. Where radar flight following proves to be impossible because of the lack of adequate signal coverage (as it might for certain vertiports located at some distance from the radar antenna) planners will need to develop procedures that permit these vehicles to manoeuvre in the vicinity of their point of origin/destination without entering into conflict with other IFR traffic.

4.3.2 En-Route Control

With respect to En-Route Control, most of the tiltrotor aircraft presently under consideration for a civil aviation application are designed to operate at cruising altitudes between 10,000 feet to 25,000 feet. This range is well below the long-haul jet routes and above the 10,000-foot level of traffic speed restrictions and corresponds roughly to the operating altitudes of current turboprop aircraft. Since the CTR would likely use the same en-route airways as turboprops, the same air traffic control measures would apply.

5. VERTIPORTS

In addition to the aeronautical infrastructure requirements discussed in section 4, the eventual implementation of CTR air services would go hand-in-hand with the development of a specialized type of "vest-pocket" airport - the vertiport. These would be small-scale facilities which would exploit the vertical take-off and landing capabilities of the CTR vehicle by being located close to the centres of demand (urban core areas, intermodal traffic hubs, other airports, etc.). Their facilities would tend to resemble those of heliports, since the take-off and landing manoeuvers, executed in proximity to the terminal area, will generally be performed in the helicopter mode; in fact, in many cases, the same VTOL site will probably serve both helicopter and tiltrotor operations.

The development of a network of more or less dedicated vertiports is seen by the FAA, NASA, the manufacturers and the local aviation authorities such as the Port Authority of New York and New Jersey, as crucial to the implementation of eventual CTR commercial air services. The above-mentioned agencies, as well as others, have studied a range of possible categories and applications of vertiports in different contexts. The present chapter describes the function of the different vertiport facilities, both airside and landside, and explains and discusses the basis for dimensional and other planning criteria.

With respect to expansion, it has been suggested that a maximum vertiport size may exist: that is to say that beyond a certain traffic level, demand would likely justify the addition of a new vertiport to the network at another demand centre.

5.1 Functional Classification

This section provides an overview of the main aspects related to the functional classification and location/configuration of different types of vertiport. Classification of vertiports will ultimately be based on the types of operations to be accommodated, the levels of activity to be expected and the size (model) of the aircraft that may be operated from the vertiport. In the NASA **CTR Missions and Applications** study, three types of functional CTR transportation systems were identified:

> **Point-to-Point**
> Under this functional system, the CTR vehicle flies directly from an origin demand center to a destination demand center, providing the most direct origin-destination service.

Through-Plane
Similar to the train and bus service concept, the through-plane concept involves one or two stop points between the origin and the destination, at which passengers may enplane or deplane.

Connecting Hub
The connecting hub is similar to existing air carrier services in that a CTR would fly from the peripheral point of departure to a hub vertiport, where passengers would connect with another CTR to reach their final destination.

5.2 Contexts of Vertiport Development

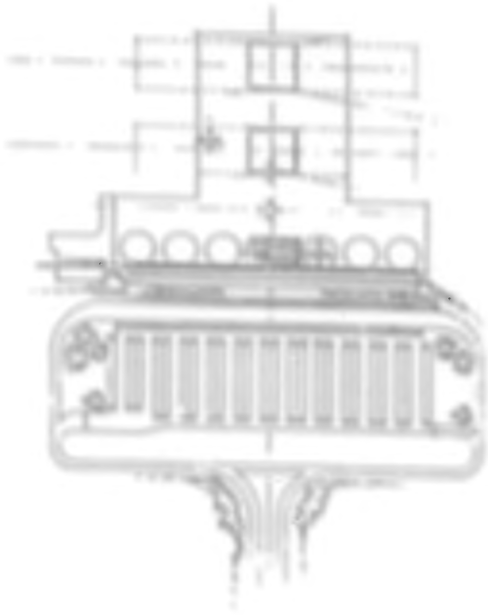
Recent studies have proposed a number of models for possible types of vertiports. In metropolitan areas, vertiports might be developed along waterfronts near downtown areas, on top of car parking structures, highway interchanges and train/bus/metro stations. Outside metropolitan areas, vertiports might be developed at land-based sites or off-shore platforms. Following is a brief description of some of these proposals. The general breakdown of vertiport types which are identified and discussed in the following pages will assist in establishing a framework for facility planning in different contexts.

5.2.1 Land-Based / Single-Level Vertiports

Whenever land is available, Land-Based/Single-Level vertiports could be developed at minimal costs at sites of approximately 25 acres. All activities would be accomplished on the same level and passengers would encounter no level changes except when boarding the airplane through covered ramps. The terminal building configuration could be compared to that of a simple linear airport terminal building. This type of vertiport would permit the landing pads to be replaced by small runways, allowing STOL operations of tiltrotors and increased payload and range. An example of this type of facility is shown in Figure 31.

As the name indicates, single-level vertiports will be developed where sufficient land area is available to provide for all types of required tiltrotor-related facilities. Expansion of such sites in urban environments may be difficult, costly or impossible; at remote or suburban locations, expansion may not pose significant problems.

FIGURE 27
LAND-BASED/SINGLE-LEVEL VERTIPORT



5.2.2 Vertiports Co-Located at Airports

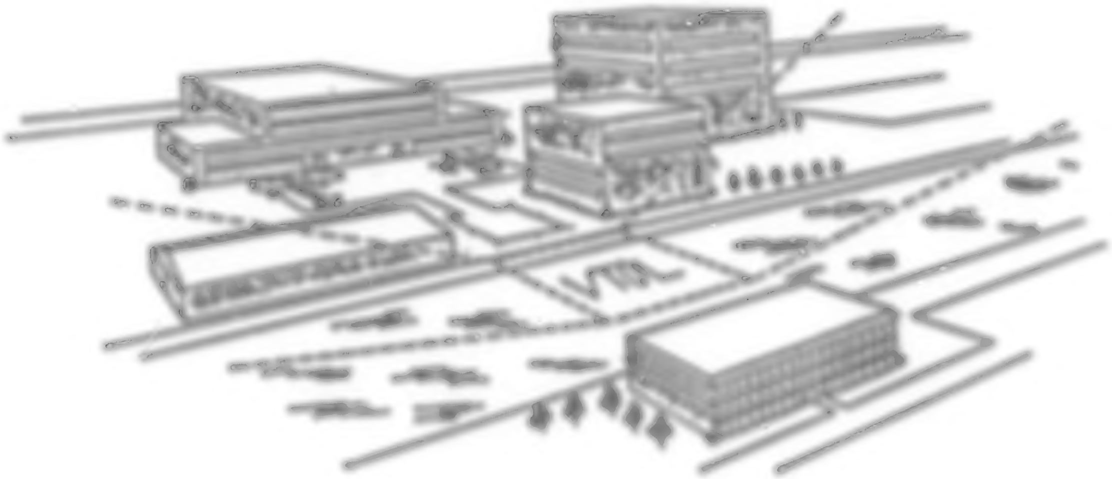
Depending on the level of activity at conventional airports, tiltrotor aircraft could use either dedicated vertiport airside facilities or common airside facilities. When separate facilities are employed, the separation between existing airside CTOL facilities and CTR dedicated facilities would have to meet specific standards in order to allow independent operations (discussed in the second volume of the present study). Commercial CTR services will in all likelihood involve stops at conventional airports as well as at stand-alone vertiports. At an airport, the vertiport would most likely offer connecting services linking tiltrotor with CTOL flights. Two possible scenarios may be found with this type of vertiport: (a) CTR would use dedicated vertiport airside facilities or (b) CTR would use common (CTR and CTOL) airside facilities. Landside facilities could be shared but, in the event that airside facilities are dedicated to one or other air mode, separate landside access would be required.

5.2.3 Waterfront Vertiports

Due to the constrained land and airspace of typical urban areas, it may be advisable to develop vertiports at waterfront sites which are available in most major cities. At present the adjacent buildings at such sites are likely to be industrial facilities or shipping warehouses, where the population densities are low compared to downtown office buildings and the unobstructed airspace available on the waterway provides advantages for aircraft operations.

Waterfront property offers a significant operational advantage in having unobstructed airspace available at least in one direction. A variant of this type, the floating vertiport, would be located offshore, accessible through connecting bridges. Figure 32 shows a waterside vertiport. Approaches and departures over water and glide slopes are free of obstructions. Operations over water would also minimize the potential annoyance of aircraft noise.

FIGURE 28
WATERFRONT VERTIPORT



5.2.4 Highway Vertiports

Highway vertiports may be seen as potential multimodal terminals. For economy of space, these types of vertiports may be located directly over highways with the facilities distributed over two levels. Some complementary facilities, not related to vertiport activities, might also be provided to accommodate other transportation modes using the vertiport. The airspace requirements would not impose any significant constraints on highway design and the environmental impacts, such as noise, would not be felt with the same magnitude as at urban vertiports.

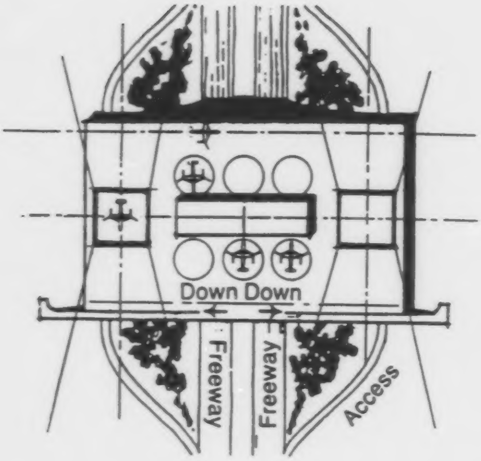
This type of vertiport makes use of unobstructed airspace already available from using highway air-rights and requires a minimum amount of additional land. The vertiport would be easily accessible by bus, automobile and rail (where applicable). Analogous to vertiports located at waterfronts, the airspace would be relatively free of obstruction.

The 1987 **CTR Missions and Applications** Study suggests the possibility of two-storied vertiports that would operate similiarly to rooftop vertiports in the sense that aircraft operations, passenger boarding and air traffic control would take place on the top deck, while ground arrival and departure curbs, ticketing areas, airline offices, car rentals, automobile parking, and access lanes would be located on the lower level. Emergency vehicles and vertiport utilities would have access to the top deck via ramps. Aircraft would be parked overnight on landing pads and at gates, leaving one landing pad and one gate free for unscheduled arrivals. Figure 29 shows such a multi-level vertiport design.

5.2.5 Rooftop Vertiports

In city centres where land is scarce, rooftops may provide appropriate locations for CTR operations provided that they comply with aeronautical requirements. Such sites offer the advantage of reducing space requirements on the rooftop landing surface by locating passenger terminal and ground vehicle curb/parking spaces on lower levels. Connection to the airside is then made by stairs or elevators which could be part of the secured area. Figures 30 shows an example of a rooftop vertiport. The scarcity and constraints of land in downtown areas may lead to a requirements for vertical separation of facilities at vertiports at such sites, leaving the top deck for airside activities only. Facilities at such sites would be limited to the strict minimum required and designed in order to comply with urban building codes.

FIGURE 29
HIGHWAY / MULTI-LEVEL VERTIPORT

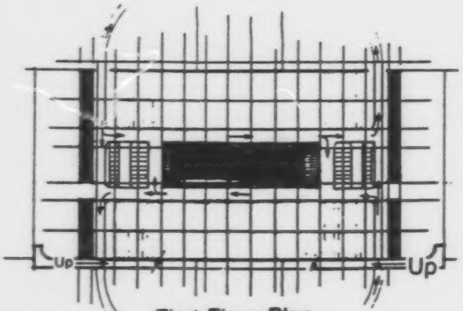

Down Down
Freeway
Freeway
Access

AIRSIDE LEVEL

FATO
APRON
CONTROL TOWER
CRASH/FIRE/RESCUE
BOARDING GATES

LANDSIDE LEVEL

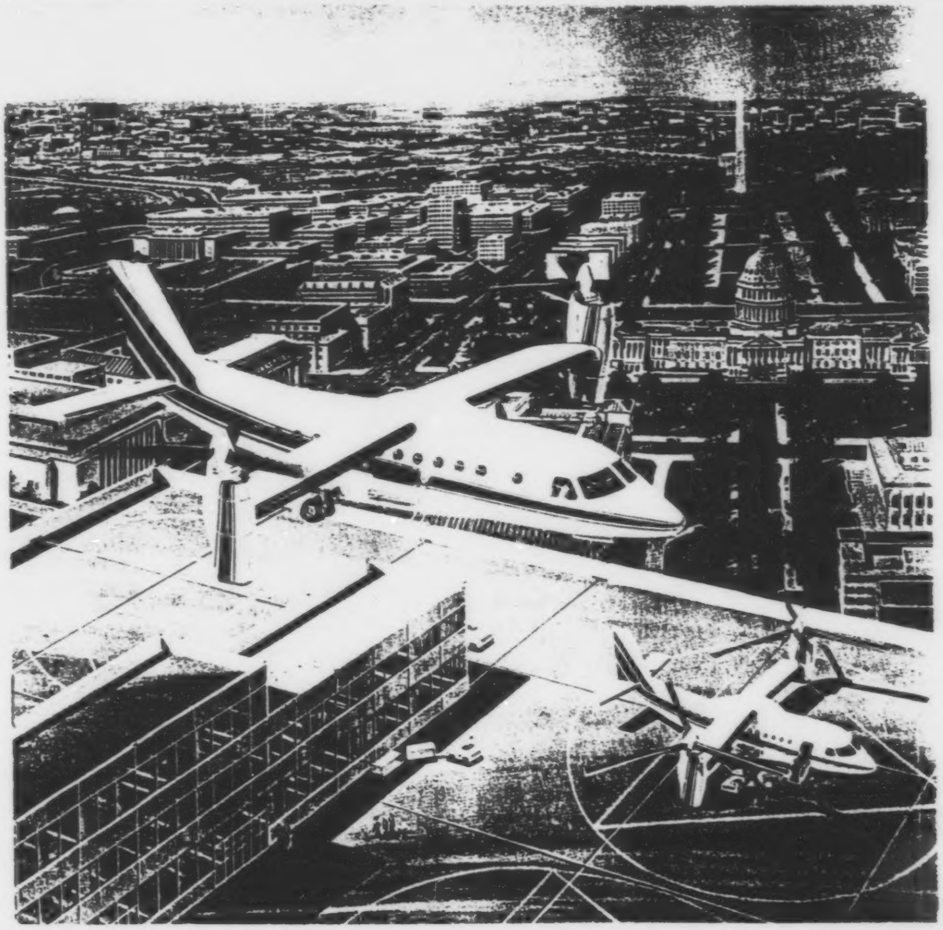
ROAD ACCESS
PARKING



First Floor Plan

PASSENGER FACILITIES

FIGURE 30
ROOFTOP VERTIPORT



5.2.6 Off-Shore Vertiports

Tiltrotor aircraft provide the means of extending air service to a wide range of off-shore sites, typically artificial platforms. Due to the severe space limitations at such locations, vertiport facilities would be limited to the absolute minimum required for safe air access. The feasibility of establishing CTR facilities at specific platforms will depend on the size and weight of the tiltrotor vehicle to be used and the structural strength of the platform.

5.3 Vertiport Airside Facilities

The prime determinant of vertiport land requirements will be the geometry and size of the airside facilities. In addition to protecting the airspace around vertiport as described in Chapter 4.1, the above-mentioned FAA Advisory Circular recommends that the vertiport authority be capable of owning or securing control over the land under the Approach Departure, and Transitional Surfaces to the point where the imaginary surfaces are at least 11 m (35 feet) above the elevation of the TLOF, as described below.

The following discussion and the suggested dimensions are principally derived from an examination and a comparison of standards found in the FAA **Advisory Circulars AC 150/53xx-xx (Vertiport Design)** and **AC 150/5390-2 (Heliport Design)**, the Transport Canada **Manual on Heliport and Helideck Standards and Recommended Practices (TP2586E)** and the ICAO **Heliport Manual (9261-AN/903/2)**. The dimensions of airside facilities account for some safety factors and are all expressed in terms of the critical vehicle dimensional variable: the rotor span of the design CTR aircraft. This uniformity simplifies the design procedures and provides an appropriate tool for comparison and understanding of the dimensional criteria.

5.3.1 Final Approach and Take-Off Area (FATO)

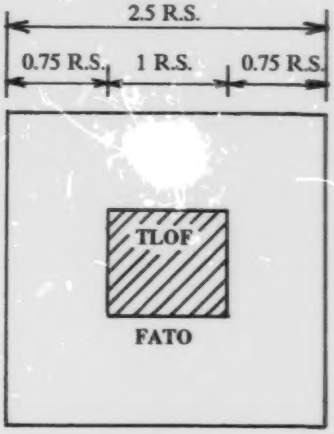
The FAA defines the FATO area as being a cleared and defined area over which the final phase of the approach maneouver to a hover or to a landing is completed and from which the take-off maneouver is commenced. It is analagous to the Runway Clear Area at conventional airports and normally contains a touchdown and lift-off (TLOF) surface. The FATO must be kept free of all obstacles above ground level.

The dimensional requirements for the FATO have generated considerable debate amoung those studing CTR planning criteria. On the one hand, it was felt that the land requirement should be kept to a minimum while on the other it felt that a short "clearway" would allow for higher lift-off weights and therefore increased payload and/or range. The FAA Advisory Circular gives specifications for a minimum facility and recommends an elongated surface where possible.

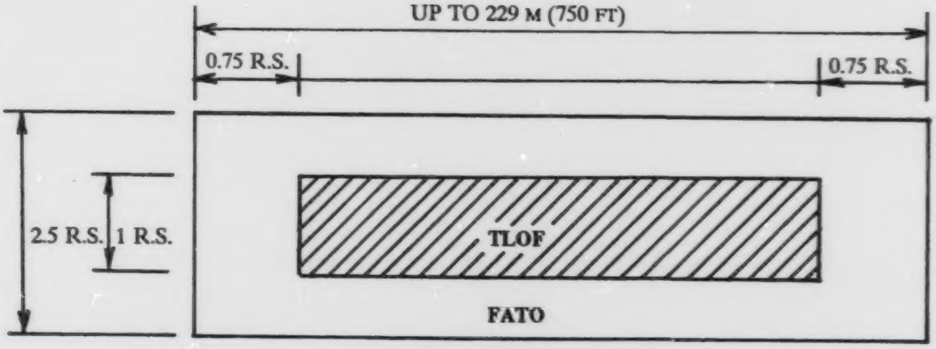
Figure 31 provides an illustration of the specific dimensional criteria for both of these configurations. As a minimum facility, the FATO would be defined as a square having sides equal to at least 2.5 times the rotor span (from tip of blade to tip of blade) of the design CTR vehicle. At sites with sufficient land area, the FATO would be defined as a rectangle having

FIGURE 31
FATO and TLOF CONFIGURATIONS

SQUARE (MINIMUM FACILITY)


2.5 R.S.
0.75 R.S.
1 R.S.
0.75 R.S.
TLOF
FATO

RECTANGULAR (ROLLING TAKE-OFF)


UP TO 229 M (750 FT)
0.75 R.S.
0.75 R.S.
2.5 R.S.
1 R.S.
TLOF
FATO

Notes:
R.S. = Rotor Span of Design Tiltrotor (tip to tip)

a minimum width 2.5 times the rotor span and a length equal to the TLOF surface plus 1.5 times the rotor span (R.S.) of the design vehicle, leaving a clearance of 0.75 R.S. between all sides of the TLOF and of the FATO limits. Because, by definition, the FATO simply needs to be "a cleared and defined area..", no specifications are made as to the size of the load-bearing portion of the area. Therefore, for economic reasons, private-use vertiports need not have a full-size load-bearing FATO like public vertiports. They may have a FATO with portions extending into unobstructed airspace.

5.3.2 Touchdown / Lift-Off Surface (TLOF)

According to definition, the TLOF is a prepared surface on which tiltrotor aircraft touchdown or lift-off. It is analogous to the Runway Surface at conventional airports. Its surface pavement must be capable of withstanding high levels of heat (reaching temperatures of 500 degrees F or more) generated by the engine exhaust which is directed down onto the pavement when the nacelles are in vertical position.

As illustrated in Figure 31, the TLOF is generally centered within the FATO and may have either a square or a rectangle configuration with one side equal to at least one rotor span. The minimum length of a rectangular TLOF suitable fo rolling take-off of a V-22 CTR vehicle has been established as 229 m (750 ft). The FAA specifies that for an elevated TLOF which is raised more than 0.9 m (3 ft) above the surrounding FATO, the TLOF must have a 1.5m (5ft) wide net along its edges.

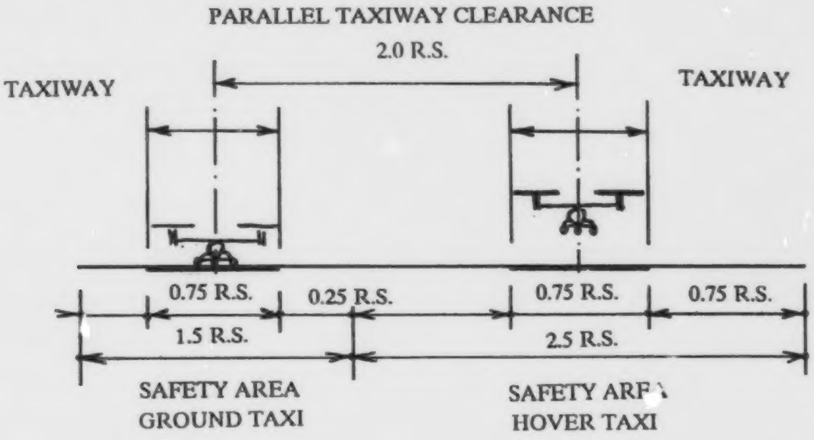
5.3.3 Taxiways

Taxiways at vertiports are not functionally different than those at airports or heliports. Taxiways are defined paths on a land aerodrome (airport, heliport or vertiport) intended for the taxiing of aircraft (fixed wing, helicopter or CTR). In the case of helicopters as well as tiltrotors, the taxiing manoeuvre can be accomplished on the ground surface or in the air, using hover mode. In either case, the taxiway stabilized paved width would be 3/4 times the rotor span of the design CTR, in order to ensure that the engine exhaust is directed onto the stabilized surface.

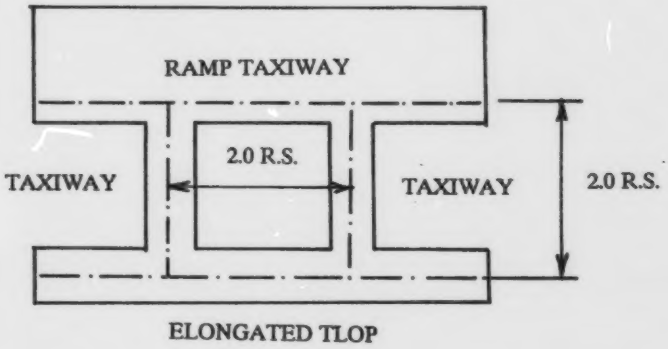
Figure 32 illustrates the critical dimensional criteria pertinent to CTR taxiway configurations. The safety area width should be at least 1.5 times the critical CTR rotor span when the vehicle is in ground taxi mode, leaving a clearance of 0.25 R.S. between the rotor tips and the edge of the taixway area. A clearance three times as large, (0.75 R.S.), is required when the

FIGURE 32
TAXIWAY CONFIGURATIONS AND HOVER TAXI ROUTES

GROUND AND HOVER TAXIWAYS


PARALLEL TAXIWAY CLEARANCE
2.0 R.S.
TAXIWAY
TAXIWAY
0.75 R.S.
0.25 R.S.
0.75 R.S.
0.75 R.S.
1.5 R.S.
2.5 R.S.
SAFETY AREA
GROUND TAXI
SAFETY AREA
HOVER TAXI

TAXIWAY & TLOF SEPARATIONS


RAMP TAXIWAY
2.0 R.S.
TAXIWAY
TAXIWAY
2.0 R.S.
ELONGATED TLOP

Notes:
R.S. = Rotor Span of Design Tiltrotor (tip to tip)

vehicle is in hover taxi mode, giving a minimum safety area width of 2.5 R.S. In the case of parallel taxiways, or when a taxiway is parallel to an elongated TLOF, the minimum distance between centerlines should be 2 R.S.

5.3.4 Aircraft Parking and Manoeuvering Areas

These areas are used for the loading, unloading, parking, fueling, and/or servicing of CTR aircraft. As opposed to the sizing of the previous facilities, which was expressed in terms of the geometrical characteristics of a single critical design CTR vehicle, the sizing of the parking and manouvering areas also reflects the degree of activity to be expected during the period of peak operations. In other words, the overall size of these areas is fixed by the number of aircraft expected to use this facility at any one time.

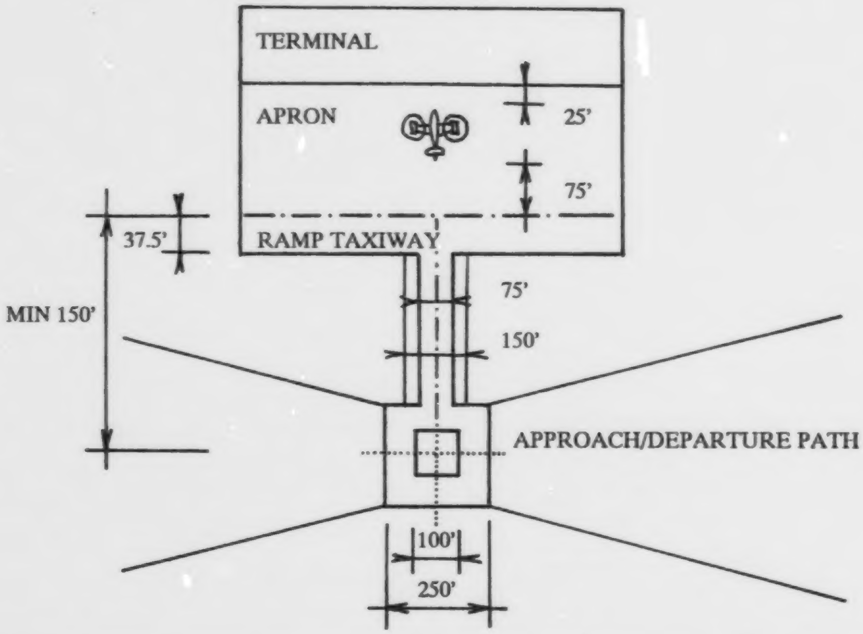
Regardless of the total level of peak period volume the planning of CTR aircraft parking and manoeuvering areas must respect established minimum clearance requirements, in order to ensure safety of passengers and apron personnel and to facilitate aircraft manoeuvering such as building structures, parked aircraft, etc. When the CTR vehicle is in ground taxi mode, a minimum separation of 7.6m (25ft) must be kept between the rotor tips of adjacent aircraft or between rotor tips and fixed or moveable objects. When in hover taxi mode, the minimum clearances should increase to 22.9m (75ft). For an apron taxiway (a selected path providing a through taxi route across the apron), the minimum requirement between the edge of the apron and the centerline of the taxiway is 11.5m (37.5ft).

Figure 33 illustrates the application of these clearences in the case a typical vertiport planned to accomodate a CTR aircraft having a 30.5m (100ft) rotor span as suggested by the FAA in the Vertiport Advisory Circular AC 150/53xx-xx.

5.4 Landside Facilities

For the purpose of the present report, the landside facilities of vertiports include all installations and services not directly related to aircraft operations. As opposed to the airside facilities, which reflect objective aircraft geometric criteria, the landside facilities will depend to a greater extent on the specific characteristics of individual vertiports (type and volume of traffic, location, presence of other activities related to vertiport development, etc.). Accordingly, one should expect a greater variety in the types and arrangements of landside installations at vertiports.

FIGURE 33
TYPICAL VERTIPORT FACILITIES



5.4.1 Passenger Terminal Facilities

The nature and extent of passenger terminal facilities to be provided at a given vertiport are a function of the types of CTR air services to be accommodated and the location and general characteristics of the vertiport in question. In terms of basic planning and design principles, the passenger terminal facilities required to serve the needs of CTR air services will have many similarities to those of typical small airports: simple, straight-forward flow patterns, multi-functional use of space, flexibility with respect to expansion and modification.

They will also reflect the requirements and preferences of the expected clientele for CTR service: a time-sensitive business-related, affluent market making short-distance, short-duration trips. In comparison with other sectors of the air travel market, these passengers will typically spend less time in the terminal building both arriving and departing, carry their baggage rather than check it, travel in smaller groups, use taxis as a prime mode of ground access, etc. In general these passengers will resemble the clientele for STOL services as documented in the reports **STOL Demonstration Montreal-Ottawa 1974-76 (TP 1687 and TP 1688)** and **STOLport Research and Applications (TP 5986)** published in 1978 and 1985 respectively.

The basic facilities to be included in vertiport passenger terminals will comprise the following (as a minimum):

- public assembly, waiting and circulation areas;
- airline counter areas(ticketing, check-in, baggage drop, baggage handling, passenger access, etc.);
- security services areas;
- departure hold areas;
- arrivals and baggage claim optional areas;
- airline support and office areas;
- commercial and public service areas;
- airport administration offices, support and building service facilities.

The configuration of the passenger terminal facilities will obviously depend greatly on the type and location of the vertiport in question. Where the land area available permits, the terminal building will generally consist of an on-grade structure at apron level; at more constrained sites (rooftops, highway spans, waterfront piers, etc.) the pasenger terminal facilities will be integrated into other structures and in some cases may well be situated at a level below that of the airfield.

5.4.2 Cargo

According to various sources, the type of cargo most likely to use CTR air services will be small parcel and courrier delivery services, such as Federal Express, Purolator, etc. It has also been suggested that CTR air cargo operations will also include general air cargo services to remote sites not accessible to CTOL aircraft. A feasibility/implementation study of a CTR air service in the Caribbean Basin centred on cargo shipments to/from Puerto Rico has been undertaken as part of a regional economic development strategy.

Taking the above into account, the characteristics and extent of cargo facilities at a given site will depend on the type of cargo service to be accommodated and the location of the vertiport. As an example, the restricted space at downtown vertiports might preclude the integration of any significant cargo operations with passenger-related activities. Dedicated cargo vertiports and, even, proprietary private-use cargo vertiports might be developed, since the cost of the land required would not be as great as for a CTOL airport. Depending on the site, cargo facilities at vertiports might require specific handling equipment for vertical movement of goods.

Vertiports located on the waterfront or over highways offer the posibility of multi-model cargo transfer terminals. As opposed to downtown vertiports, these vertiports might be able to integrate cargo and passenger activities. At land-based/single-level vertiports, cargo facilities will be comparable to typical small airport cargo facilities.

5.4.3 Aircraft Maintenance Facilities

Only those vertiports with sufficient land area (land-based/single-level sites and co-located at airports) will include full-service aircraft maintenance facilities. The relatively extensive space requirements of such facilities will preclude their location at downtown vertiports. Only overnight aircraft maintenance and emergency repairs will be performed at these sites, and these operations will take place at the aircraft parking positions. At less constrained sites, hangars in which aircraft maintenance is done may also serve for aircraft storage at night.

5.4.4 Fire and Crash Rescue (FCR)

Vertiports certified for public use will have to provide the appropriate level of fire and crash rescue (FCR) services in compliance with the relevant standards for the site (Transport Canada, FAA, ICAO, etc.). The larger land-based/single-level vertiports will likely include conventional airport fire stations similar to those found at typical small airports. All facilities and operations being located and performed on a single level will favor such systems.

Elevated vertiports, however will need to adopt new methods of fire and crash rescue. Because operational surfaces are limited, it might be different or even impossible to establish such stations. Instead, alternatives such as fire nozzle systems might be considered. In any case, some sort of rescue vehicle will be required. At the rooftop vertiports, this vehicle would be on the top deck at all times while at waterfront and highway vertiports, the vehicle might have access via ramps connecting the lower levels to the top deck in case of emergency.

5.4.5 Fuel Storage

The requirements for the storage of aviation fuel vary widely depending on the location of the site. At land-based/single-level vertiports fuel storage facilities will be similar to those at typical small airports. All of the other locations identified as potential vertiport sites will require careful attention when planning for such facilities, especially in urban vertiports where the surrounding population may be very dense and where the safety aspect is of prime importance and a keystone of any "good neighbor" policy.

Preferably no fuelling should be allowed at such sites unless the type of service and level of demand is such that it becomes a necessity. In such cases new types of storage systems might be developed, taking into consideration the elevation to which fuel would have to be pumped up to the top deck and the type of structure required to ensure protection from fuel leaks and spills.

5.4.6 Commercial Facilities

The novelty of the tiltrotor technology will in all likelyhood make the CTR and its vertiport a point of attraction for the public. It is also possible and in some cases likely that vertiports will form parts of multi-modal transportation hubs and/or mixed-use urban development projects (e.g. as proposed by the Sealander Group in Washington DC, and the Convention Center in Dallas). This, together with the relative accessibility and proximity of the vertiports sites to the surrounding community offers commercial business opportunities such as restaurants, stores, and advertising, etc. In urban sites, these commercial opportunities may even generate revenues in excess of those generated by aeronautical activities and the development of this potential may be a prerequisite to the establishment of vertiports at such sites.

5.4.7 Ground Access and Car Parking

The wide range of sites suitable for vertiports (downtown, waterfront, highway) expand the practical possibilities for ground access modes as compared with conventional airports. Modes such as taxis, metro and other rail systems, courtesy vehicles, buses will likely play a greater role vis-à-vis private cars, although these will have to be accommodated at any site.

Access to the surrounding road network will involve simple junctions or interchanges at more remote land-based sites. At some of the more complex sites, such as rooftops of buildings and car parks, highway rights-of-way, etc. access will be via a series of ramps; special curb space could be reserved so as to give priority to taxis and public transit users. An underground metro and rail stations could also be located below the vertiport structures thereby increasing the potential basin of attraction. Similarly for waterfront vertiports, the possibility of water access might increase the potential basin of attraction.

In the case of vertiport sites in proximity to or co-located with metro, rail and/or bus stations, people-mover systems such as escalators or elevators might be required for access to and from the vertiport.

6. ENVIRONMENTAL CONSIDERATIONS

If CTR air services are to fulfill their promise of providing enhanced point-to-point air service in a wide variety of contexts, including dense urban areas, they will have to demonstrate their environmental compatibility. In Canada, a number of federal, provincial and municipal statutes require that projects such as the construction of vertiports/heliports or the introduction of new transportation services such as CTR submit to an environmental review before obtaining certification, funding and/or authorization for implementation.

6.1 Noise

Noise generated by aircraft operations (especially those of rotorcraft) constitutes the most significant source of public environmental concern related to the introduction of tiltrotor air services, especially in urbanized areas. There has been a substantial amount of research done on noise generated by aircraft operations in general. Several methods exist for the measurement and prediction of noise exposure as well as for the assessment of noise for land use planning purposes. The present section provides an overview of the current status of information on noise specifically related to tiltrotor operations.

6.1.1. Sources and Propagation of Tiltrotor Noise

The sources of noise generated by tiltrotor aircraft are similar to those of both rotorcraft and turboprops and may be categorized under four major headings:

(1) propulsion system noise;

(2) typical propeller noises (such as blade-loading, blade-thickness and self-noise);

(3) typical helicopter noises (such as blade-loading, blade-thickness, self noise, blade-wake-interaction (BWI), blade-vortex-interaction (BVI), turbulence ingestion and re-ingestion);

(4) mutual aerodynamic and aeroacoustic interactions, due to rotor/rotor and rotor/wing interactions and geometry changes.

The propulsion system noise is basically the engine noise, which includes the noise generated by the burners, compressors, etc. The engine noise from the CTR is comparable to that generated by turboprop engines. The blade-loading noise is generated as a result of the force produced by the blades, while the blade-thickness noise is generated as the blade "cuts" the air mass. These two latter types of noise create a pressure pulse (resulting from very high pressure changes) that is perceived as a distinct noise by the human ear.

The BWI and BVI are generated by the rotary motion of the blades. As a blade strikes the wake of its predecessor, it makes a so called BWI noise; similarly, the BVI noise is created when the blade tip strikes the vortex wake that was produced from the previous blade tip. The self-noise, as well as the turbulence ingestion are mainly due to the boundary layer in the flow. They are generated when the aircraft crosses the air flow (winds, air pockets). The flow reingestion noise is created by the rotating wake which comes back and which is swept down by the wing.

The wake-flow patterns of tiltrotor aircraft and the noise which they produce are complex phenomena which vary considerably according to the mode of operation (vertical, horizontal, transitional) as illustrated in Figure 34.

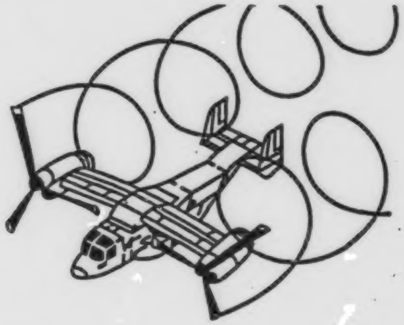
The propagation of noise generated by aircraft is related to the flight profiles and characteristics of the vehicle under operating conditions. In the case of tiltrotor aircraft in particular, the extent and type of noise emanating from the aircraft varies considerably depending on whether the vehicle is in vertical flight mode, horizontal flight mode or in transition between the two.

When flying in horizontal flight mode, observations to date indicate that tiltrotor aircraft will generate noise with characteristics similar to that of advanced turboprop aircraft, with a generally lower level of disturbance. This is due to the slower rotational speed of the large proprotor blades in comparison with standard turboprops. In the vertical flight mode, observations indicate that the tiltrotor exhibits noise characteristics similar to helicopters, depending on operating procedures. As opposed to helicopters, however, CTR aircraft will limit this type of noise to the relatively short and physically confined vertical flight segment of the mission, while the greatest extent of overflights will be in the quieter turboprop mode.

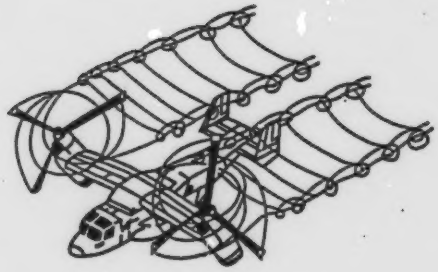
The ultimate extent of the noise propagation relative to a specific CTR operation will be related to the time spent, the altitude, the power required and the horizontal distance covered in each flying mode. Figure 35 provides a diagrammatic illustration of a typical CTR mission, indicating the different types of noise propagation corresponding to the various flight segments and modes of operation.

FIGURE 34
TILTROTOR WAKE FLOW PATTERNS

AIRPLANE MODE



TILT ROTOR MODE



HOVER MODE

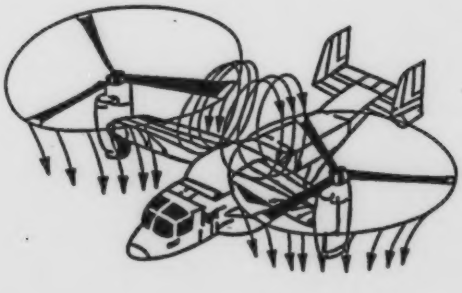
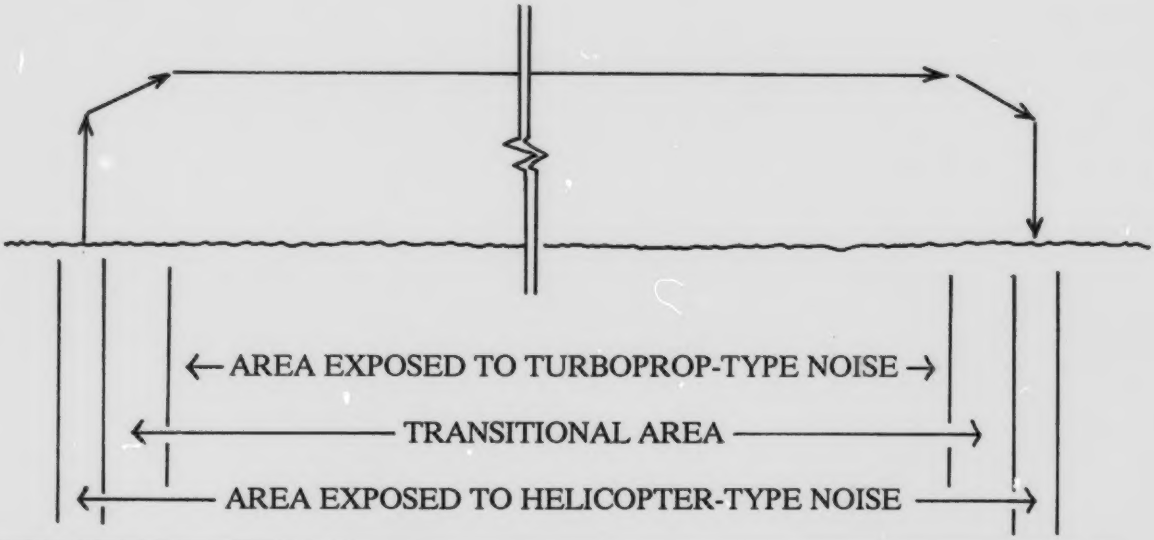


FIGURE 35
NOISE PROPAGATION DURING TYPICAL CTR MISSION



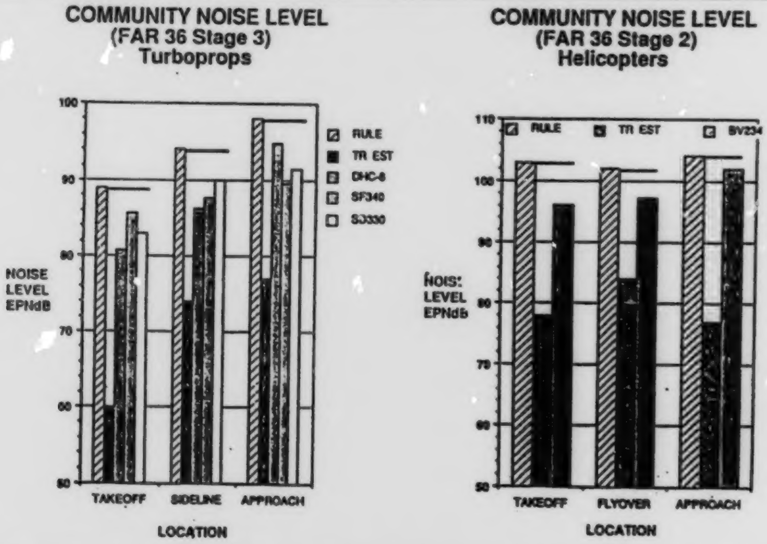
← AREA EXPOSED TO TURBOPROP-TYPE NOISE →
← TRANSITIONAL AREA →
← AREA EXPOSED TO HELICOPTER-TYPE NOISE →

6.1.2 External Noise Levels and Impact

Studies to date indicate that the extent and levels of noise generated by civil tiltrotor aircraft will meet standards for community acceptance established by civil aviation authorities and will have less overall impact than either turboprop or helicopter aircraft. For example, the NASA CTR Missions and Applications study of 1987 has shown that the community noise levels, expressed in terms of effective perceived noise decibels (EPNDB), are significantly lower than those stipulated in the relevant FAA rules for both fixed wing (FAR Part 36, Stage 3) and rotary wing (NPRM, 14 CFR) aircraft. Figure 40 provides a graphic comparison of estimated CTR community noise levels with those of typical current turboprop and helicopter aircraft as well as with the relevant FAA noise certification rules.

Figure 37 shows the estimated 80dBA ground-level noise contour, (which is considered to be the maximum acceptable residential level) for a typical tiltrotor. This figure indicates quite clearly the relatively small area subject to noise levels greater than this. It should be noted that these estimated community noise levels were based on a propeller aircraft noise prediction model developed by Bell-Boeing, with adjustments to reflect the CTR situation based on available information and on estimated CTR data.

FIGURE 36
TILTROTOR/VERTIPORT NOISE

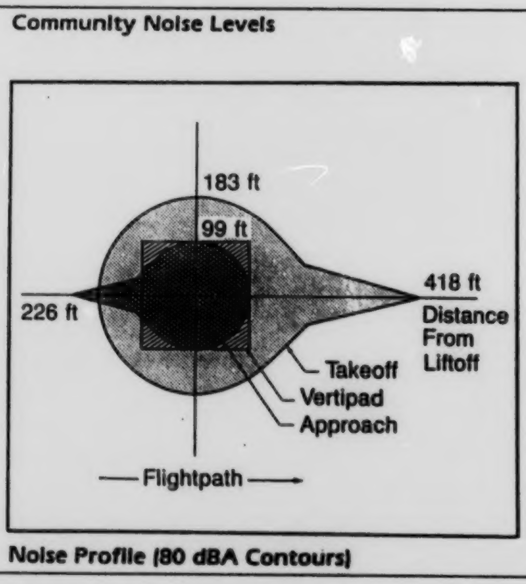


COMMUNITY NOISE LEVEL
(FAR 36 Stage 3)
Turboprops

COMMUNITY NOISE LEVEL
(FAR 36 Stage 2)
Helicopters

SOURCE: NASA

FIGURE 37
GROUND-LEVEL NOISE CONTOUR FOR A TYPICAL CTR



Community Noise Levels

183 ft
99 ft
418 ft
226 ft
Distance From Liftoff
Takeoff
Vertipad
Approach
Flightpath

Noise Profile (80 dBA Contours)

SOURCE: NASA

6.1.3 Measurement and Prediction of Tiltrotor Noise Impact

The measurement and prediction of the noise impacts of tiltrotor aircraft operations present a problem for planners at this time, due to the limited availability of test data and the unique nature and characteristics of this noise. With respect to the former, at this point NASA has only attempted to provide preliminary estimations of CTR noise, since no direct measurements have yet been made for the V-22. Direct measurements of V-22 noise data should be available in 1992, depending on the progress of the current V-22 R+D programmes. In the meantime, measurements of noise generated by the XV-15 experimental tiltrotor aircraft have been used as a basis for estimating the eventual noise impact of other CTR vehicles by extrapolation.

With respect to the estimation of noise related to CTR operations at or around vertiport sites, there is reason to believe that the existing prediction models may not take into account the special characteristics of the tiltrotor aircraft and, therefore, may not give an accurate indication of CTR noise impact on surrounding communities. A number of such models exist and are used by civil aviation authorities throughout the world. Transport Canada, for instance, uses the Noise Exposure Forecast (NEF) model; the FAA uses a similar tool referred to as the Integrated Noise Model (INM). Transport Canada has applied the NEF model in the case of noise predictions for a heliport in Canmore Alberta, but the results have not been tested and a number of anomalies were observed in the results. U.S. authorities have developed a specialised variant of the INM: the Helicopter Noise Model (HNM), which takes into account the specific noise characteristics of helicopters.

None of these approaches is likely to give representative results for tiltrotor operations. Accordingly, the Bell-Boeing consortium has indicated its intention to develop a specific tiltrotor noise prediction model, the "VNM", that would combine elements of the INM and HNM. As well, noise contours adapted for specific tiltrotor vehicles are also planned to be developed. No concrete results are expected before the end of one or two years of intensive work.

In addition to research directly related to the V-22, the NASA Langley Research Center is developing a full-system rotorcraft noise prediction computer program referred to as ROTONET. As one of the four elements of the NASA Aircraft Noise Prediction Program (ANOPP), ROTONET, once completed, will have the ability to predict a rotorcraft noise signature from basic input data on rotorcraft geometry and operating conditions. The ROTONET programme consists of several modules belonging to four different phases:

Module 1	produces computations of the performance and tone noise for an isolated main rotor or isolated tail rotor;
Module 2	provides the added capability for a more detailed performance analysis required for the prediction of tone and broadband rotor noise;
Module 3	processes the added capability of predicting several additional noise sources;
Module 4	adds one module which predicts the far-field noise signature from two rotors arbitrarily placed in space and a second module which incorporates a methodology for prediction of Blade Vortex Interaction noise suitable for system noise prediction studies.

Progression through these phases enables more sophisticated rotorcraft performance calculations and subsequent to this, more sophisticated source noise calculations, as well as the addition of more source noise mechanisms. Far-field acoustics tests were conducted on an experimental XV-15 tiltrotor aircraft in order to create a high degree of confidence and an accurate far-field acoustics data base to be used in the validation of ROTONET. The results have shown an overall trend to some variables for both the airplane mode and helicopter mode. Better agreement with data comparisons is expected with the use of the more advanced phases of the prediction system.

Once reliable data, based on predictions and confirmed with real observations, is available to the FAA, a Notice of Proposed Rule Making will be initiated and should then be ready two or three years thereafter. The NPRM will include new standards and will be a sub-part of the FAA FAR Part 36. An ICAO sub-group serves as a medium by which a joint government/industry working group is considering the issues.

6.1.4 Effect of Noise on Siting of Vertiports

Since the major benefits of CTR as a future commercial air transportation mode result from the ability of the aircraft to land and take-off close to the centres of passenger demand and, therefore, in proximity to the communities served, potential disturbance due to aircraft noise will constitute a critical issue in the siting of vertiports.

For CBD vertiports, tiltrotor noise may not pose a significant problem since it will likely be mixed with the relatively high level of ambient noise produced by other urban activities, such as traffic and truck circulation. Similarly, vertiports located at waterfront sites may not generate undue annoyance since these sites are often occupied by industries, factories or shipping warehouses. In more suburban settings, vertiport sites may well pose problems due to the lower levels of ambient noise and the greater extent of residential and other noise-sensitive land uses.

6.2 Security and Safety

As with all forms of aircraft, the security and safety of CTR vehicles represent an important environmental concern. This is especially so since the public will likely perceive all advanced VTOL aircraft in the same way as helicopters, which suffer at present from an unfortunate negative perception as "dangerous flying machines" having a high probability of falling out of the sky in OEI situations.

6.2.1 Flying Concerns

As mentioned in the first volume of this study, tiltrotor technology is not new. The concept has been validated with the XV-15 and again with the V-22. It is foreseen that several safety features will be included in the CTR. Triple redundant flight controls, hydraulic systems, and electrical systems should ensure fail-safe operations while a unique cross-shaft between transmissions will ensure that one engine, alone, can power safe flight operations. The presence of these CTR safety features should enable CTR services to operate at a high level of safety in OEI situations, therefore reducing the extent of area required for emergency landings.

Public education programmes and live demonstrations should be planned in order to alleviate this fear and to facilitate the integration of CTR in the communities which will benefit from the new services. At certain potential sites, a number of environmental factors might have an influence on the safety of flights. This is especially true for night operations at downtown vertiports located on elevated platforms surrounded by other such structures. In these cases, vertiport lighting would need to be highly visible and identifiable so as to avoid any confusion for the pilot between city lighting (streets and buildings) and that of the vertiport itself and to avoid collisions with unlighted buildings.

6.2.2. Bird Strikes

Because air space is shared between birds and other flying objects, bird strikes with tiltrotors will be another environmental concern. In the case of jet aircraft, bird strikes can cause considerable damage to the aircraft engine to the extent that the engine is totally destroyed and the aircraft literally falls out of the sky.

Bird strikes with tiltrotors will be different as the amount of air mass captured by the rotors is significantly less than that ingested by jet engines. In addition, the tiltrotor blades turn at a far lower rate. The bird will simply pass through the rotating blades and then fall; the blades, therefore, should not suffer disabling damage. While bird strikes with tiltrotors are less damageable than with jet aircraft, the probability of occurrence is higher than that of bird strikes with helicopters. The capture area in the CTR case is much larger because the rotors are vertical as opposed to horizontal as is the case with helicopters.

Vertiports located on the waterfront might be subject to higher potential hazards as birds often reside close to these areas. Similarly, vertiports over major highways might be places where the presence of birds is highly probable. The grass and trees or crop fields along highways often attract birds; accordingly, selection and preparation of sites for safe operations should be a critical planning task. In downtown areas, land uses such as parks, and, in some cases building architecture might encourage the presence of birds. If a vertiport is to be located on a new building, the architects, during the planning stage, should take care to ensure that architectural features which attract birds are not present. It should be noted that in the immediate proximity of the vertiport site, the likelihood of a bird strike for CTR operations would be similar to that for helicopter operations since the CTR would essentially operate in that mode.

6.2.3 Fire Safety

One other aspect of environmental security concern is that of aviation fuel and fire safety. This is especially true for elevated vertiports in populated areas (Minutes of the FAA / Industry Joint Vertiport Working Group Meeting; November 16, 1989). It should be possible to properly and promptly contain spilled fuel in order to avoid contamination of essential services (such as water supply) and damages to the structure beneath the vertiport. Fire rescue and protection will also be important because of its close proximity to occupied high-rise buildings and to densely populated areas. Special disaster prevention techniques will need to be developed.

6.3 Ground Traffic

The generation of traffic by ground mode to and from airports constitutes one of the environmental concerns relative to air transportation in general. This traffic is generated not only by passengers, but also by employees, cargo, and visitors. In the case of some of the larger airports, this induced ground traffic can represent a significant problem at the local level, due to the sheer volumes of traffic generated and the concentration of road traffic on a limited number of constrained facilities which must often serve both airport and other users. The introduction of CTR services will have an impact on the generation of ground traffic related to air services in the areas of concern outlined in the following paragraphs. These concerns are essentially related to vertiports in urban settings, as opposed to remote sites.

The most significant point to be made concerning ground traffic generation by urban CTR services is that they represent a decentralisation of air transportation. For the most part, the CTR clientele would use small vertiports located close to the centres of demand instead of much larger conventional airports located at some distance from local passenger origins and destinations. As a result, the introduction of CTR air services will tend to encourage the distribution of airport-induced ground traffic relatively evenly throughout the local transportation network, as opposed to concentrating traffic at a few restricted points.

Ground traffic is not likely to be much affected by downtown vertiports. Besides new trip generation rates, no major changes in the urban transportation system are foreseen. In the near future, because the demand level for CTR activity will be relatively low, the optimum size of the aircraft being for 31 passengers (see Volume I), increases in local ground traffic volumes will not be substantial. Contrary to airports, vertiport growth would likely be limited to a maximum practical level. When the demand reaches a certain level at a given site, another vertiport would probably be justified at another location. Generation of ground traffic would thus be maintained at a defined level with limited impact on road network capacity and levels of service.

6.4 Air Pollution

Air pollution represents one of the potential environmental concerns relative to all forms of air transportation and in this sense CTR air services are no different from others. At present knowledge of the extent of aircraft emissions from the full range of expected CTR vehicles is limited to experience with the XV-15 and the V-22 and to design data for the various other models.

In the case of tiltrotor operations, air pollution is generated essentially by two sources: (1) engine emissions and (2) turbulence-induced dust during lift-off and touch-down manoeuvers. According to the NASA study of 1987, the engine emission levels for CTR aircraft are expected to be acceptable and will not contribute significantly to general levels of air pollution. The CTR feasibility study for the state of California is scheduled to include analysis of air quality and aircraft emissions to serve as a basis for identifying the impacts and benefits of implementing CTR service. According to the study terms of reference, the expected levels of engine emissions will be based on the latest available data on individual vehicle emissions, forecasts of air traffic throughout the system and the types of operations in question.

With respect to dust raised by the rotor down-wash and ground turbulence during lift-off and touch-down, neither the volume generated nor the area affected is expected to be significant. Impact of this phenomena is easily controllable by effective design of the vertiport airfield surfaces and proper operational practices, thus limiting or virtually eliminating the danger of surface erosion and the formation of dust clouds during landing, take-off and hover taxi operations.

6.5 Energy Consumption

6.5.1 Background

The present chapter discusses consumption of energy by tiltrotor aircraft in the general context of energy use by transportation modes in Canada. Data for this purpose were obtained directly from the Boeing Commercial Airplane Group (joint manufacturer with Bell Helicopter Textron of the V-22) and from the Transport Canada document **Energy and Environmental Factors in Intercity Passenger Transportation** (TP10198).

The amount and type of energy use for transportation purposes is potentially significant. In general, transportation consumes more petroleum than any other sector of the economy, accounting for over 65% of the total consumed in Canada in 1989. Of this amount, approximately one quarter was consumed for intercity passenger transportation, primarily by the automobile and air modes (63% and 35% respectively).

Our market analysis (Chapter 7 of the present report) indicates that the principal application of tiltrotor as a transportation mode in Canada will be in the Quebec - Windsor corridor. We have therefore used energy consumption figures for the other transportation modes operating in this environment as a basis for comparison with analogous figures established by the manufacturers for the tiltrotor aircraft. Including tiltrotor, the modes used for comparative purposes in the Quebec - Windsor corridor were:

- CTR-22C (V-22 derivative)
- CTR-7500 (new technology)
- air (turboprop)
- air (jet)
- rail (LRC)
- intercity bus
- private automobile

6.5.2 Components of Energy Consumption

Tiltrotor aircraft, like the other previously mentioned intercity travel modes in Canada, use petroleum fuel as a source of energy for propulsion of the vehicle. This end use is referred to as *direct energy*. It is not, however, the only component of energy use for transportation purposes. The other requirements, referred to collectively as *indirect energy*, can account for between 26% and 34% of the total energy consumed, depending on the individual mode. For the purposes of the present analysis, total energy consumption for intercity passenger transportation includes the following components:

- direct energy
  - vehicle propulsion
- indirect energy
  - energy production and distribution
  - vehicle production
  - vehicle maintenance
  - infrastructure construction
  - infrastructure maintenance
  - terminal access

Specific figures for direct energy consumption in the air mode (tiltrotor, turboprop and jet) were taken from basic data supplied by Boeing. Corresponding data for other modes were taken from the above-mentioned Transport Canada document (TP10198). We have adapted these figures in order to present them in terms of kilo-joules per seat-km. They are sensitive to both the technology of the vehicles and the nature of the routes being served. The figures used in this analysis were based on the general system characteristics of the short-haul network involving Toronto, Montreal, Ottawa and Quebec City.

Figures for indirect energy consumption were taken from TP10198 and modified according to the judgement of the consultants for the tiltrotor mode. Indirect energy required for the production and delivery of the fuel to the vehicle is derived as a percentage of the level of direct energy consumed and is dependent on the generic type of vehicle and fuel used, tiltrotor being classed as aircraft for this purpose. Indirect energy required for production and maintenance of the tiltrotor was calculated on the basis of an assumed increase of 20% above similar figures for STOL aircraft based on discussions with Boeing. With respect to indirect energy required for construction and maintenance of the infrastructure associated with the tiltrotor mode, figures for the terminal requirements were assumed to be identical to those for turboprop and STOL aircraft, while the runway system requirements were assumed to be 1/3 of those for STOL aircraft. Energy requirements for tiltrotor terminal access were based on automobile energy consumption figures and assumed average access distances similar to those for rail and intercity bus terminals.

6.5.3 CTR Energy Consumption Comparison

The Table 8 presents a comparison of basic unit energy consumption figures for tiltrotor and other modes of transportation in the Quebec - Windsor corridor, in terms of kilo-joules per seat-km and kilo-joules per passenger-trip depending on the particular parameter.

TABLE 8
ENERGY CONSUMPTION BY MODE FOR SHORT-HAUL INTERCITY PASSENGER TRAVEL

	CTR 22C	CTR 7500	AIR TURBO	AIR JET	RAIL LRC	INTERCITY BUS	AUTO-MOBILE
Direct Energy							
Vehicle Propulsion (kj/seat-km)	2774	1935	1207	1387	406	386	558
Indirect Energy							
Energy Production and Distribution (kj/seat-km)	349	244	152	175	51	49	109
Vehicle Production (kj/seat-km)	61	61	29	29	33	20	185
Vehicle Maintenance (kj/seat-km)	181	181	90	90	64	52	115
Infrastructure Construction							
. Terminal (kj/pax)	16 600	16 600	16 600	41 000	46 215	9 140	n.a.
. Civil (kj/seat)	6 000	6 000	18 000	64 000	865	80/km	80/km
Infrastructure Maintenance							
. Terminal (kj/pax)	83 000	83 000	83 000	206 000	98 430	15 800	n.a.
. Civil (kj/seat)	1 167	1 167	3 500	9 640	63/km	10/km	10/km
Access (kj/pax)							
. Mtl-Tor.	52 020	52 020	156 060	156 060	55 080	58 140	n.a.
. Tor.-Ott.	52 020	52 020	146 880	146 880	55 080	52 020	n.a.
. Mtl-Ott.	36 720	36 720	88 740	88 740	36 720	36 720	n.a.
. Mtl-Que	36 720	36 720	107 100	107 100	39 780	36 720	n.a.

7. POTENTIAL APPLICATION OF CIVIL TILTROTOR IN CANADA

The choice of a particular mode of transport is a result of a number of interacting factors such as: trip length, trip purpose, cost of transport, speed, comfort, reliability, safety, etc. Four travel modes, namely - automobile, airplane, bus and train - represent the basic practical choices applicable for intercity travel in Canada today.

Based on an extensive and comprehensive market analysis, and also on an evaluation of CTR technology, the FAA, NASA and others have concluded that a commercial tiltrotor operation is technically feasible, economically competitive and has a potentially significant role to play in civil air transportation. Due to its unique capabilities and enhanced in-flight characteristics, the CTR vehicle offers significant advantages in a number of applications when compared with conventional fixed-wing or rotating-wing aircraft. The NASA/Bell-Boeing studies **Civil Tiltrotor Missions and Applications: A Research Study** (1987), and **Phase II: The Commercial Passenger Market** (1991) as well as other documents, identified the following specific areas in which the application of CTR technology would seem to offer advantages over other modes of transportation:

- Short-Haul Commercial Air Passenger Market
- Resource Development Market
- Public Service Market
- Corporate/Executive Market
- Cargo/Package Express

The main objective of this section is to apply general findings and conclusion of the above-mentioned studies to the Canadian context. The study concentrates on the high-density city-centre to city-centre short-haul markets in order to identify city pairs which because of their particular interdependence, geographical relationships and level of air passenger travel demand they generate, could likely benefit from introduction of regular CTR service. The findings of this exercise are presented in section 7.1 which follows. The secondary objective is to provide an overall review of the extent to which the other CTR applications mentioned above relate to the Canadian context. This review is presented in section 7.2.

7.1 Application of CTR Technology in Intercity Passenger Transportation

7.1.1 Criteria for Commercial CTR Passenger Service

Short-haul intercity air travel in many densely-populated parts of the world is currently experiencing difficulties due to considerable delays encountered on a daily basis caused by growing congestion both in the air and on the ground near existing airports: a situation which could, in many cases, be referred to as multi-modal gridlock. The capacity of ground and air access systems into and out of airports is being saturated and there does not seem to be any easy solution to resolve this problem, which has serious implications in terms of the safety, reliability and productivity of air transportation. With the traffic increases expected before the end of this century, this situation will continue to deteriorate.

In Canada, although many airports will not experience this congestion problem for many years, those which do so at present, Toronto and Vancouver, are those which handle the greatest volumes of air traffic in Canada. Any increase in over-all door-to-door travel time is especially critical in the area of short-haul air transport where any significant delays could virtually eliminate the advantage of air transportation to the travelling public. The level of attractiveness of CTR is among other things influenced by the cost of providing the service. The higher per seat acquisition and operating costs of CTR in comparison to CTOL will necessitate a higher level of airfares in comparison with those charged for turboprop and jet service. FAA/NASA studies concluded that despite higher "air cost" CTR service would be competitive with existing fixed-wing operations in short-haul markets where convenience and time-saving are important.

Due to the in-flight flexibility of the CTR vehicle, vertiports can be located close to the centres of traffic demand and the aircraft can operate independently from CTOL air traffic in terminal airspace environments. This offers the possibility of (1) improving door-to-door service to passengers in dense short-haul markets and (2) alleviating both air and ground traffic congestion. Vehicle cruise speed and total travel time are two factors defining the geographic extent of the market area which could be effectively served by CTR. This effective range defines, on the one hand, the distance beyond which CTOL jet service would represent a more efficient travel alternative for point-to-point passengers and on the other hand the distance below which ground modes could prove to be an advantageous choice for the majority of travellers. For the purpose of our analysis, the present market review assumes a cruise speed of approximately 300 knots, and a 1 hour trip time as general parameters for the effective range of commercial tiltrotor passenger service. This combination of speed and air travel time defines an effective mission radius for CTR commercial intercity passenger service of some 550km.

CTR service would not be intended to replace all present CTOL service on short-haul air routes. This is neither practical nor desirable. A number of short-haul flights are in fact legs of longer routes; also a number of air passengers use short-haul flights to connect to other destinations. As stated above, CTR intercity service would be intended to cater to a specific segment of the market by offering a new type of air service which conventional fixed-wing turboprop and jet aircraft cannot offer. According to a study for the New York Port Authority, the estimated maximum market potential of tiltrotor air passenger service in the New York area would involve the capture of 1/3 to 2/3 of the high-density short-haul air travel market.

In order to be commercially successful, however, CTR service would have to meet certain criteria necessary to ensure the unique competitive advantages of the technology. A large segment of the potential CTR clientele consists of business people travelling between major commercial centres. Their key concern is time. Therefore, a successful CTR service would have to be oriented towards minimizing overall door-to-door travel time. The following parameters will have direct impact:

- **Vertiport physical location** - Vertiports would have to be located close to the markets they serve in order to minimize time and out-of-pocket expenses related to the ground portion of the over-all door-to-door trip and, thus, to maximize the CTR market potential. The present study does not include the evaluation of the availability of appropriate vertiport sites in the specific Canadian cities identified as potential candidates for CTR service. The present study assumes that such sites would be available.

- **Vertiport intermodal integration** - Vertiports would have to be well integrated into the local multi-modal transportation network in order to function effectively as an inter-modal transfer point. All forms of local transportation must have convenient and easy access to the local vertiport in order to maximize market exposure. The study assumes that all vertiports under consideration will be adequately integrated.

- **CTR level of service** - A combination of aircraft seating capacity and frequency of service defines the minimum market size required to support CTR service. In order to be commercially successful, the capacity of the CTR system would have to be carefully tuned to the actual size of the market being served and would have to offer a frequency of flights competitive with parallel CTOL services. For the purpose of this study, an aircraft size of 39 seats and frequency of service of 30 and 60 minutes are used.

- **CTR all-weather capability** - CTR service would have to offer all-weather, reliable and safe service comparable to that of CTOL. In fact, the special capability of the tiltrotor to independently control vertical and horizontal speed of movement in the final approach provides greater potential for all-weather landings than CTOL aircraft. The study assumes that all scheduled services will be operating under IFR regime.

- **CTR airspace** - On a national basis, regional tiltrotor networks serving the major metropolitan areas, including the heliports and hub airports will have to be designed and put into place to allow safe and reliable operations into urban centres and busy airports on a non-interference basis in order to realize the potential of reducing air traffic delays on a system-wide basis. The present study assumes that no difficulties will be encountered in the establishment of the most direct and safe air routes to be allocated for scheduled tiltrotor service.

- **Passenger comfort** - CTR service will have to offer all amenities and services now provided by CTOL service. Passenger and baggage handling procedures at vertiports will have to be streamlined in order to minimize in-terminal time, thus reflecting the fact that the service would be geared to those clients who assign a high value to their time. The study assumes that the overall level of passenger comfort will be at least equivalent to that of CTOL business class.

In order for CTR commercial passenger service to fulfil its role as a premium short-haul transportation mode, it would have to present both real and perceived differences in the efficiency of the service relative to other available short-haul travel modes. The ultimate goal of providing multiple-point services in metropolitan areas would be developed in stages, starting with centre-to-centre services.

7.1.2 CTR Intercity Passenger Markets in Canada

The purpose of the present document is to indicate the likely role of CTR services in Canada in terms of the extent of the network of services and terminals and the magnitude and nature of the clientele. More specifically, the following pages describe the city-pairs which would constitute the network of CTR intercity passenger services in Canada, the passenger volumes on each link and fleet sizes involved, as well as the approach used in determining this data. We have used an iterative approach in our analysis based on the notion of applying a series of criteria regarding the minimum conditions necessary to create the basis for economical air services from an airline perspective. The iterative process is graphically illustrated in Figure 38.

The application of the basic service parameters listed in Table 9 enables the determination of a minimum size for a commercial CTR operation which would satisfy the service criteria described in the previous section (7.1.1) to this document. This section summarizes the basic assumptions regarding the operational characteristics of a CTR air service system. For the purpose of this analysis two market categories were identified: primary (or stand-alone) and secondary (or add-on). From the point of view of market size, a primary market is defined as a CTOL market of such a size as to permit the introduction of CTR service as a self-standing competitive mode of transport between two specific points. A secondary market is defined as a market of such a size as to justify the introduction of CTR service only in the case when at least one of the two service points is already equipped with a vertiport and is enjoying regular CTR service. In such cases, CTR services might be added on as expansions of an existing self-standing service.

Step 1

The analysis of Canadian air travel markets as described above resulted in the identification of the primary intercity markets suitable for introduction of CTR services strictly on the basis of the assumed ability of CTR services to compete and successfully penetrate a developed CTOL air market, in accordance with the criteria and parameters listed in Table 9.

The potential vertiport hubs in Canada were identified on the basis of intercity air traffic volumes forecast for the years 2000 and 2010 and CTR service parameters of air route length and a calculated minimum or threshold size of air market. Due to the fact that CTR service is limited to the short-haul market only, the evaluation of potential air markets was limited to domestic and transborder traffic sectors.

The baseline forecast used in the analysis was prepared by Transport Canada. It takes into consideration travel demand on the business as well as non-business segments of the air market and provides details for specific city pairs.

City-pairs were first selected on the basis of traffic volumes forecast for the year 2010. We have calculated a threshold volume of at least 725 000 O/D business air passengers as a precondition for the introduction of CTR services in a primary or stand-alone market. An air distance criterion of 185 - 556 km was then applied to eliminate those outside this range. Thus, the primary CTR markets and potential hubs markets were identified for the years 2000 and 2010. This methodology is illustrated graphically in Figure 39 and the results presented in Table 10.

Step 2

In Step 2 other opportunities are evaluated for the introduction of CTR services which might exist due to special circumstances but would not be supportable as primary or stand-alone services relying only on penetration of observed existing CTOL activity. Demand in these secondary (or add-on) markets would include both penetration of ground modes and CTOL, as well as the induced traffic generated by the introduction of additional CTR services and vertiports associated with the primary markets.

FIGURE 38
GENERAL APPROACH TO CTR MARKET ANALYSIS

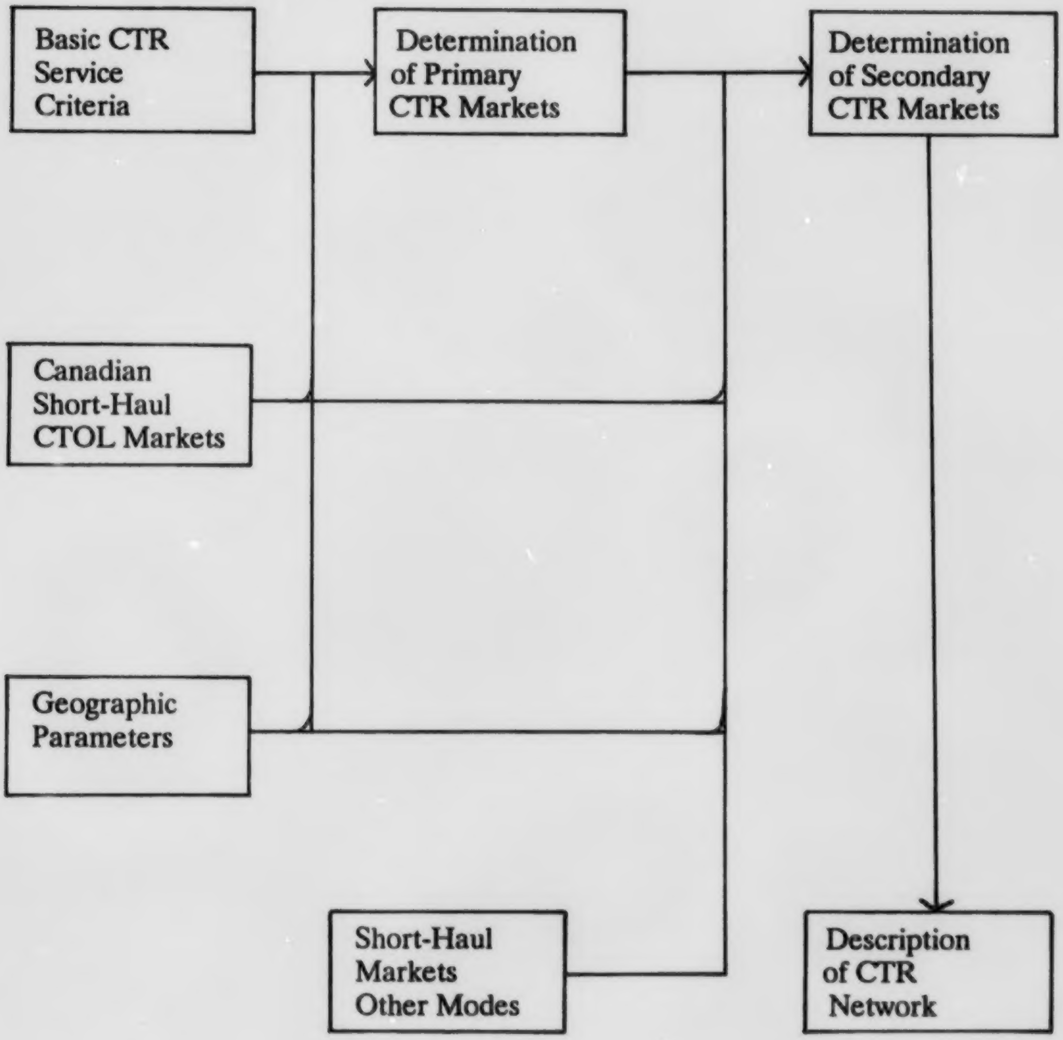

Basic CTR Service Criteria
Determination of Primary CTR Markets
Determination of Secondary CTR Markets
Canadian Short-Haul CTOL Markets
Geographic Parameters
Short-Haul Markets Other Modes
Description of CTR Network

TABLE 9
SUMMARY OF CTR MARKET ANALYSIS CRITERIA AND PARAMETERS

Aircraft seating capacity	39 seats
Aircraft effective range[1]	
. minimum air route length	185 km
. maximum air route length	356 km
Average block time	60 min
Daily operating hours	07h00 - 22h00
Minimum required service frequency	
. to initiate CTR service[2]	30 min
. to expand CTR service[3]	60 min
Variation in level of service weekday vs weekend day	3 : 1
Number of weekdays in a year	250 days
Average annual utilization per aircraft	2300 hours
Average annual load factor	70%
Penetration of CTOL O/D air market	
. 30 min frequency of service	2/3 of the market
. 60 min frequency of service	1/3 of the market

---

[1] Effective range from a marketing point of view vis-à-vis other available modes of travel.

[2] Establishment of new vertiports at both ends of a route.

[3] Expansion of CTR service based at an existing vertiport and establishment of a new vertiport at the new service point.

Resulting CTR Intercity Network

Applying the above-mentioned basic criteria of trip length, market size, service frequency, aircraft size and effective range of CTR vehicles to the Canadian context resulted in the identification of a number of high-density primary markets with potential CTR service hubs: Toronto, Montreal, and Ottawa. Feeder points would consist of Quebec and other points in Southern Ontario. Further, these networks would be linked to similar systems in the U.S.

Table 10 summarizes the Primary Markets and the following paragraphs provide additional notes on individual routes. Table 11 summarizes the individual markets on each route and indicates the degree of penetration of the CTOL market. Table 12 indicates the annual CTR flight activity which would be generated on the main links of this system.

Primary CTR Intercity Passenger Markets

Toronto - Montreal / Toronto - Ottawa / Toronto - New York

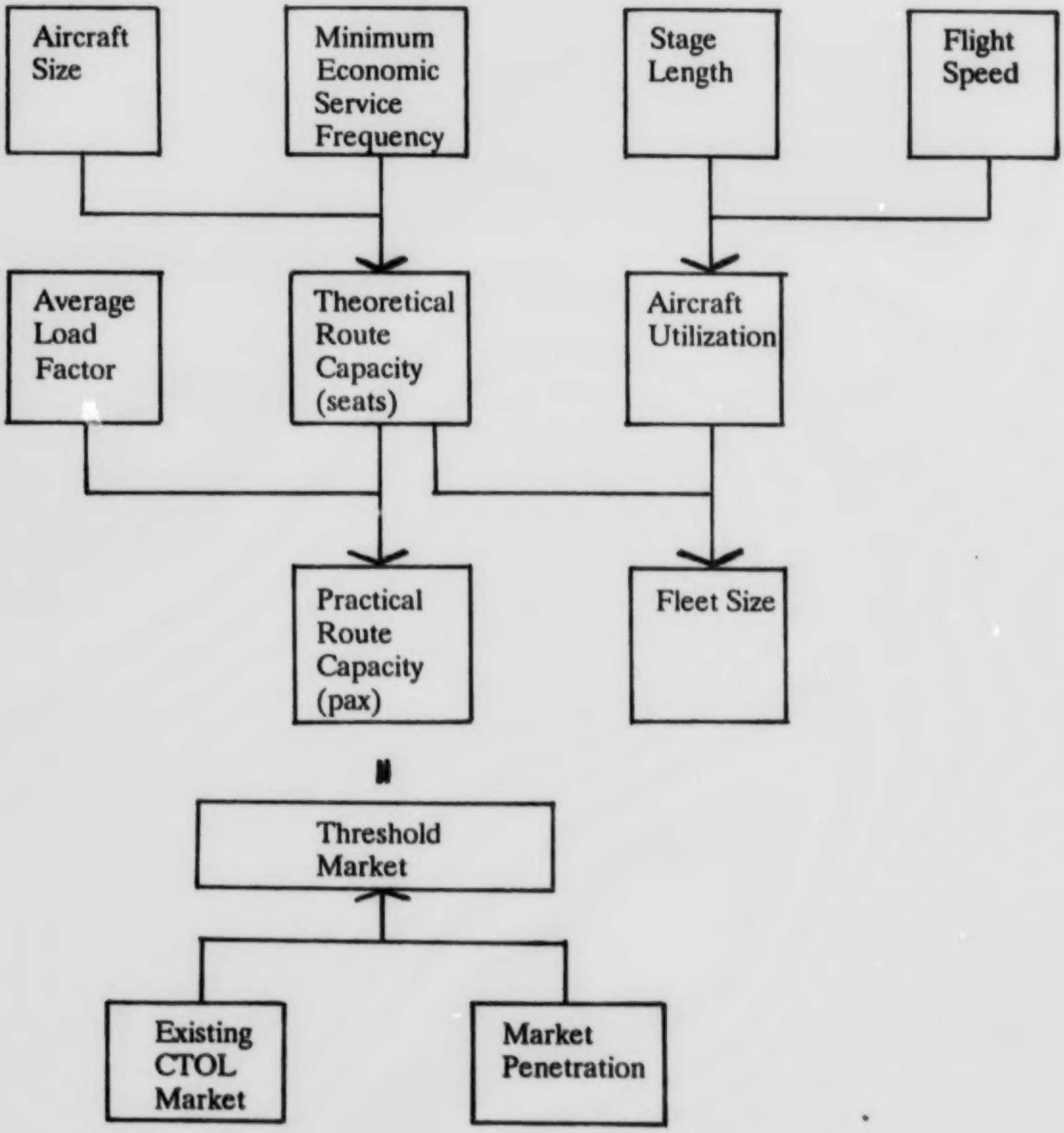
- Intercity markets most suitable for introduction of CTR services due to:
    - overall size
    - type of clientele (business)
    - stage length
- No strong argument to support significant penetration of other modes of transportation

Secondary CTR Intercity Passenger Markets

Montreal - Ottawa / Montreal - Quebec City

- High potential for significant penetration of both air and ground modes
- Ease of introduction of service once vertiports at Montreal and Ottawa developed to support Toronto services
    - type of clientele (business / government)
    - distance
- Inconvenient CTOL site at Quebec City

FIGURE 39
DETERMINATION OF PRIMARY CTR THRESHOLD MARKETS


Aircraft Size
Minimum Economic Service Frequency
Stage Length
Flight Speed
Average Load Factor
Theoretical Route Capacity (seats)
Aircraft Utilization
Practical Route Capacity (pax)
Fleet Size
=
Threshold Market
Existing CTOL Market
Market Penetration

Toronto - Windsor (Detroit) / Toronto - Washington D.C. / Toronto - Cleveland /
Montreal - New York / Montreal - Boston

- Potential exists for service expansion from Toronto and Montreal to US cities within effective CTR range, once those US cities are equiped with vertiport facilities

- Rather than "full day" shuttle service assumed for primary markets, these markets would be served via limited service designed to maximize utilization of existing fleet of CTR vehicles.

Vertiports

The network would include vertiports at the above-mentioned Canadian cities. The volume of traffic at Toronto and Montreal would eventually justify two vertiport sites in these metropolitan areas in the years 2000 and 2010 respectively. Ottawa and Quebec City would each have one vertiport. Table 13 indicates the level of traffic at these points. Table 14 summarizes the vertiport activities in the Canadian CTR network as a whole, including both domestic and transborder routes.

TABLE 10
SUMMARY OF POTENTIAL CANADIAN INTERCITY CTR MARKETS

City-Pair	O/D Market Size (business trips x 1000) 1987	2010	Threshold Year[1]	Stage Length (km)	Within CTR Economic Range[2]
Montreal-Toronto	1215	3200	attained	509	yes
Ottawa - Toronto	793	2250	attained	365	yes
Victoria - Vancouver	349	790	2007	63	no
Calgary - Vancouver	255	525	2010 +	685	no
Toronto - Windsor	103	255	2010 +	315	yes
Montreal - Quebec	69	160	2010 +	233	yes
Calgary - Edmonton	301	590	2010 +	248	yes
Edmonton - Vancouver	204	400	2010 +	809	no
Vancouver - Kelowa	107	235	2010 +	287	yes
Vancouver - Prince George	83	145	2010 +	522	yes
New York - Toronto	503	1200	1995	559	yes
New York - Montreal	236	575	2010 +	532	yes
Chicago - Toronto	230	510	2010 +	695	no
Boston - Toronto	127	300	2010 +	717	no
Vancouver - Seattle	138	355	2010 +	204	yes
Cleveland - Toronto	51	125	2010 +	311	yes
Detroit - Toronto	48	120	2010 +	343	yes
Boston - Montreal	150[3]		2010 +	407	yes
Toronto - Washington D.C.	118[3]		2010 +	558	yes

[1] Year when CTOL volume equals precondition for primary CTR services, i.e. 725 000O/D busines trips

[2] CTR economic range equals approximately 185 (minimum) to 556 (maximum) kilometres

[3] 1988 O/D Business + Non-Business

FIGURE 40
POTENTIAL MAJOR CANADIAN INTERCITY CTR MARKETS

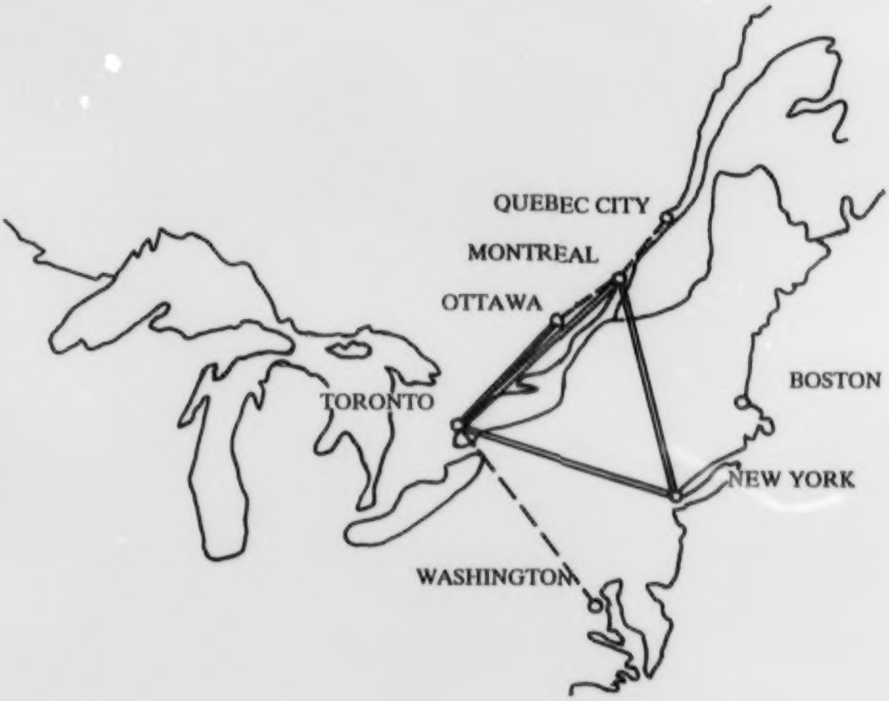

QUEBEC CITY
MONTREAL
OTTAWA
TORONTO
BOSTON
NEW YORK
WASHINGTON

TABLE 11
CANADIAN CTR MARKETS AND PENETRATION OF CTOL

City-Pair Routes	Annual CTR Passenger Volume (x1000)		Penetration of Total CTOL O/D Markets	
Year	2000	2010	2000	2010
Toronto - Montreal	1575	2150	61	60
Toronto - Ottawa	1150	1500	66	63
Toronto - New York	600	800	40	39
Toronto - Washington D.C.	125	250	67	67
Montreal - Ottawa	250	350	90	90
Montreal - Quebec	250	350	90	90
Montreal - New York	275	400	44	47

TABLE 12
CTR EN-ROUTE FLIGHT ACTIVITY

City-Pair (site)	Aircraft in Service 2000	Annual Flights 2000	Aircraft in Service 2010	Annual Flights 2010
Toronto (1) - Montreal (1)	14	29000	10	21000
Toronto (1) - Montreal (2)	-		8	17500
Toronto (2) - Montreal (1)	13	27000	10	21000
Toronto (2) - Montreal (2)	-		8	17500
Toronto (1) - Ottawa	10	21500	13	27000
Toronto (2) - Ottawa	9	19500	13	27000
Toronto (1) - New York	5	10750	8	18250
Toronto (2) - New York	5	10750	5	10750
Toronto (1) - Washington D.C.	2	4500	4	9000
Montreal (1)- Ottawa	4	9000	6	12500
Montreal (1)- Quebec	4	9000	6	12500
Montreal (1)- New York	5	10000	8	14500
Total Airspace Load		146500		208500
Total Aircraft in Service	71		99	

TABLE 13
VERTIPORT TRAFFIC ACTIVITIES: CANADIAN CTR NETWORK

City/Vertiport	Routes	Annual Passengers	Annual A/C Movements	Annual Passengers	Annual A/C Movements
		2000		2010	
Toronto	Montreal (1)	815 000	29 000	600 000	21 000
Vertiport 1	Montreal (2)	-	-	475 000	17 500
(downtown)	Ottawa	600 000	21 500	750 000	27 000
	New York	300 000	10 750	500 000	18 250
	Washington D.C.	125 000	4 500	250 000	9 000
Total Vertiport 1		1 840 000	65 750	2 575 000	92 750
Toronto	Montreal (1)	760 000	27 000	600 000	21 000
Vertiport 2	Montreal (2)	-		475 000	17 500
(off-downtown)	Ottawa	550 000	19 500	750 000	27 000
	New York	300 000	10 750	300 000	10 750
Total Vertiport 2		1 610 000	57 250	2 125 000	76 250
TOTAL TORONTO		3 450 000	123 000	4 700 000	169 000
Montreal	Toronto (1)	815 000	29 000	600 000	21 000
Vertiport 1	Toronto (2)	760 000	27 000	600 000	21 000
(downtown)	Ottawa	250 000	9 000	350 000	12 500
	Quebec	250 000	9 000	350 000	12 500
	New York	275 000	10 000	400 000	14 500
Total Vertiport 1		2 350 000	84 000	2 300 000	81 500
Montreal	Toronto (1)	-	-	475 000	17 500
Vertiport 2	Toronto (2)	-	-	475 000	17 500
(off-downtown)					
Total Vertiport 2		-	-	950 000	35 000
TOTAL MONTREAL		2 350 000	84 000	3 250 000	116 500
Ottawa	Toronto (1)	600 000	21 500	750 000	27 000
	Toronto (2)	550 000	19 500	750 000	27 000
	Montreal (1)	250 000	9 000	350 000	12 500
TOTAL OTTAWA		1 400 000	50 000	1 850 000	66 500
Quebec City	Montreal (1)	250 000	9 000	350 000	12 500

TABLE 14
SUMMARY OF VERTIPORT ACTIVITIES: CANADIAN CTR NETWORK

City/Vertiport	Annual CTR Passengers	Annual Aircraft Movements	Annual CTR Passengers	Annual Aircraft Movements
	2000		2010	
TORONTO				
Toronto (1)	1 840 000	65 750	2 575 000	92 750
Toronto (2)	1 610 000	57 250	2 125 000	76 250
Total	3 450 000	123 000	4 700 000	169 000
MONTREAL				
Montreal (1)	2 350 000	84 000	2 300 000	81 500
Montreal (2)	-	-	950 000	35 000
Total	2 350 000	84 000	3 250 000	116 500
OTTAWA				
Total	1 400 000	50 000	1 850 000	66 500
QUEBEC CITY				
Total	250 000	9 000	350 000	12 500
CANADIAN CTR NETWORK				
Domestic	6 450 000	230 000	8 700 000	312 000
Transborder	1 000 000	36 000	1 450 000	52 500
Grand Total	7 450 000	266 000	10 150 000	364 500

TABLE 15
VERTIPORT PLANNING REQUIREMENTS

City/Vertiport	Design Hour Aircraft Movements		Gates Required	
	2000	2010	2000	2010
TORONTO				
Toronto (1)	16	22	6	7
Toronto (2)	14	18	5	6
Total	30	40	11	13
MONTREAL				
Montreal (1)	20	19	7	7
Montreal (2)	-	8	-	3
Total	20	27	7	10
OTTAWA				
Total	12	16	4	6
QUEBEC CITY				
Total	2	3	2	2
TOTAL CTR NETWORK				
Grand Total	64	86	24	31

7.2 Other CTR Technology Applications

In addition to its potential attractiveness and significance as a vehicle for short-haul commercial air passenger transportation in high density markets, planners in the US and Europe have identified a number of other applications. The following sections provide an assessment of the potential for these applications in Canada.

7.2.1 Air Passenger Service to Remote Regions

The ability of tiltrotor aircraft to fly medium-range missions at turboprop speeds with virtually no runway requirements points to a potentially valuable role for CTR as a vehicle to enhance and extend the reach of air passenger service in remote regions. The vast majority of the area of Canada falls into this category. Apart from the relatively limited zones of high concentration of population in the southern part of the country, the rest of Canada is sparsely populated with a limited transportation infrastructure.

This is especially true in the northern regions, where the air mode is already well established as the only practical means of year-round transportation of persons and goods. In fact, the ability to ensure air service to these areas under adverse conditions relates directly to the development of their economic potential, the provision of social services and even to the maintenance of national sovereignty.

The special characteristics of the northern environment pose a number of serious operational and economic problems for conventional air transportation, both fixed wing and helicopter. Population densities are low and therefore, services are limited and infrequent. At the same time, the severe weather conditions, long winters and permafrost ground upheavals make the construction and maintenance of runway facilities (snow removal, grading, etc.) extremely expensive in relation to the frequency of service.

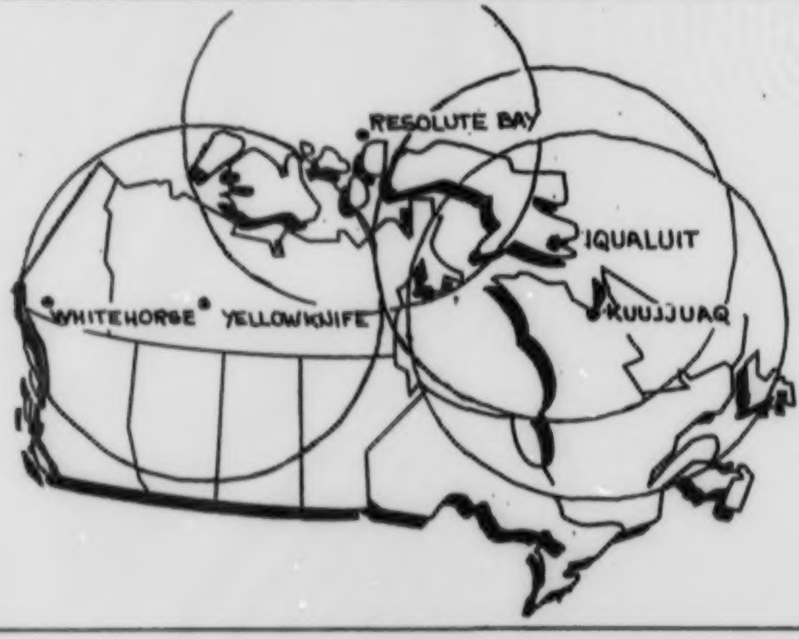
The use of tiltrotor technology as a replacement for fixed-wing aircraft would substantially reduce the construction and maintenance costs of airport facilities, by minimizing runway length requirements and lowering the stringent requirements relative to surface conditions of landing areas. While tiltrotor requirements for landing areas are comparable to those of helicopters, the distances involved in typical northern missions are outside the range of helicopters and, therefore, helicopter service in the North is limited to specific local functions. The introduction of CTR will thus significantly extend the provision of services to the population.

In fact, the operational characteristics of tiltrotors, such as their extended range, improved all-weather capability, cruise speed, and minimum requirements for landing facilities, makes CTR an ideal air support mode for service in the Canadian North. Well-established northern hubs, connected with southern Canada by regular jet service could become bases for CTR northern operations. For the purpose of this discussion, the following four northern hubs were identified to be logical choices in order ensure full coverage of the northern remote regions of Canada.

- Kuujjuaq - for services in northern Quebec
- Frobisher Bay - for services in the Baffin Island area
- Yellowknife - for services in the western Northwest Territories
- Resolute Bay - for services in the far north

In addition to significantly reducing the operational and maintenance costs which would be associated with conventional airfields, the advantage of CTR would be felt in the significant reduction of the capital expenditures required to open a far greater number of new northern air service points which would be required for equivalent helicopter service.

FIGURE 41
CANADIAN NORTHERN TILTROTOR MARKETS



7.2.2 Support of Resource Exploration and Development

The resource exploration and development market has been identified as another interesting opportunity for the application of tiltrotor technology. This market in Canada consists essentially of off-shore oil and gas exploration and development, logging, mining and general resource exploration. Perhaps the best potential for immediate introduction of CTR is in air support of oil and gas exploration and development.

Most of Canada's oil and gas reserves are found in Western Canada. However, they represent only slightly more than one percent of Canada's identified resources. There are vast untapped resources in Northern Canada and off-shore along the East Coast. Timely exploration and development of new oil and gas reserves are paramount to assure that Canada will be self-sufficient in energy in the future.

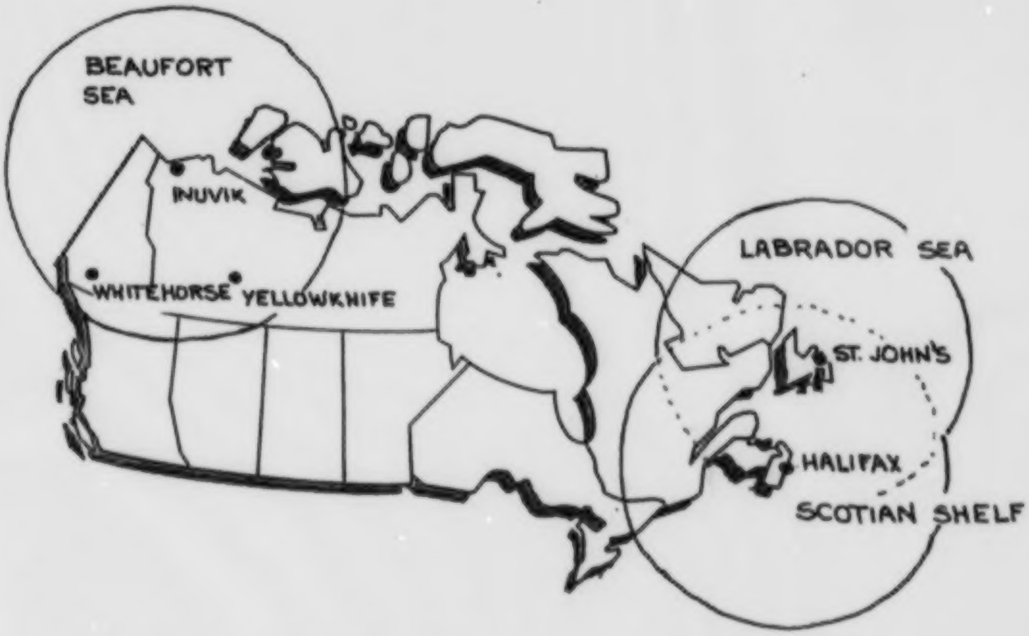
For the purpose of this discussion, four specific off-shore exploration / development areas in Canada are considered. These are: the Scotian Shelf, centred on Sable Island, Nova Scotia; the Hibernia Fields, off-shore from Newfoundland; the Labrador Sea; the Beaufort Sea in the far North.

Air support is a critical transport mode used for moving personnel and supplies between off-shore platforms and the on-shore support and supply bases. The current state-of-the-art air transportation in off-shore development is represented by the familiar helicopter shuttle services now operating between platforms and on-shore staging centers and supply bases in various parts of the world. In fact, this is the most successful world market for large helicopters.

While this service can be satisfactory under certain circumstances, its efficiency is limited to applications where trip stage lengths are rather short (typically in the range of 50 - 100 nautical miles). A major problem associated with helicopters is a significant loss of productivity when longer trip stage lengths are involved. Average cruise speed and maximum flight range are two limiting factors.

These two limiting factors for helicopters represent, in fact, the two major advantages of CTR in the context of its application in off-shore support. These become especially significant as the stage length of trips between on-shore bases and off-shore platforms increases.

FIGURE 42
CANADIAN OFF-SHORE TILTROTOR MARKETS



Due to the higher cruise speed of the vehicles, a smaller fleet of CTR vehicles of comparable size would be required to accomplish identical tasks to those performed by helicopters. Further, because of its substantially longer range (up to 600 nautical miles) a smaller number of supply bases would need to be deployed in order to serve adequately the same off-shore platforms using CTR vehicles, and these platforms could also be situated in locations which might not be feasible within the range limitations of helicopters.

CTR operating costs compare well with those of state-of-the-art helicopters, now under development, such the EH-101, and are substantially lower than those of current models. In addition to the savings obtained from lower aircraft operating costs, significant economies could be realized by resource development companies due to reduced payroll costs, resulting from reduced in-transit time of crews during regular bi-weekly rotations of platform personnel. These can be quite significant.

Weather conditions along the Atlantic coast and in the Beaufort Sea are quite severe and often limit the deployment of helicopters to or from platforms. Because of their limited speed, helicopters are more likely to miss a "window" in the weather pattern which a faster and longer-range CTR vehicle could utilize in order to accomplish a mission which would otherwise have to be aborted. Disruption of primary platform activities due to the constraints of weather conditions obviously has a negative impact on the efficiency and economy of the entire resource development operation. The question of efficient, safe and reliable air access to off-shore resource development platforms is significant given the economic and strategic importance of this sector in Canada.

A number of proposals have therefore been made to overcome the constraints of range, speed and operating cost which seem to be inherent in helicopter operations. In 1982, a TDC-sponsored study entitled **Alternative Air Transportation Facilities for Off-shore Energy Resource Development** examined the possible use of a floating airport as a means of improving transportation services for off-shore platforms. This floating air hub, acting as a transfer point, was designed to be serviced from shore points by Dash 7 STOL aircraft and from off-shore platforms by helicopters and represented a compromise solution intended to match the higher cruise speed and longer range of turboprop aircraft with the vertical flight capability of helicopters in providing access to remote individual platforms. The use of tiltrotor aircraft would obviate the requirement for such a facility which was estimated in the study to cost some $200 to $500 millions in 1985 dollars.

The extent of application of CTR in other sectors of resource development is not as clear. More market analysis work is required in order to identify comparative costs and benefits vis-à-vis currently used modes. However, it is quite clear that the speed, range and hover capabilities of tiltrotors will be the three primary factors favoring this technology over fixed-wing or helicopter aircraft. Pressurized cabins are not seen as a necessity in this particular market. It is therefore possible and indeed likely that the first generation of CTR vehicles (involving minimum modifications to the current V-22 models) will be eminently suitable for this market.

7.2.3 Public Services

The public services market places the greatest demand on the capabilities of the vehicle, due to the wide range of different types of missions required to be performed in this market. In this sector, the ultimate customer is the general public. Public services are generally provided free of charge by agencies on a when-and-if-required basis. The costs are typically borne by a wide base, including federal, provincial and/or municipal governments, depending on the provider of the particular service. The following sub-sectors of public service were identified as those which would benefit directly from the introduction of CTR technology.

Medical Transport

The use of CTR would improve the efficiency of missions currently requiring transfers between helicopters and fixed-wing aircraft for total trip stage lengths beyond the range of helicopters. This would improve the quality of in-transit care by eliminating the need for transfers between vehicles and substantially reducing total in-transit time between the medical intervention point and the hospital facility. The longer range and higher speed of tiltrotors further increases the effective area which could be effectively served by a particular medical facility. For the purposes of medical transport, a hypothetical eight-passenger model with a pressurized cabin, referred to as the CTR-800, has been identified by planners in the U.S.

Forest Fire Fighting / Disaster Relief / Search and Rescue

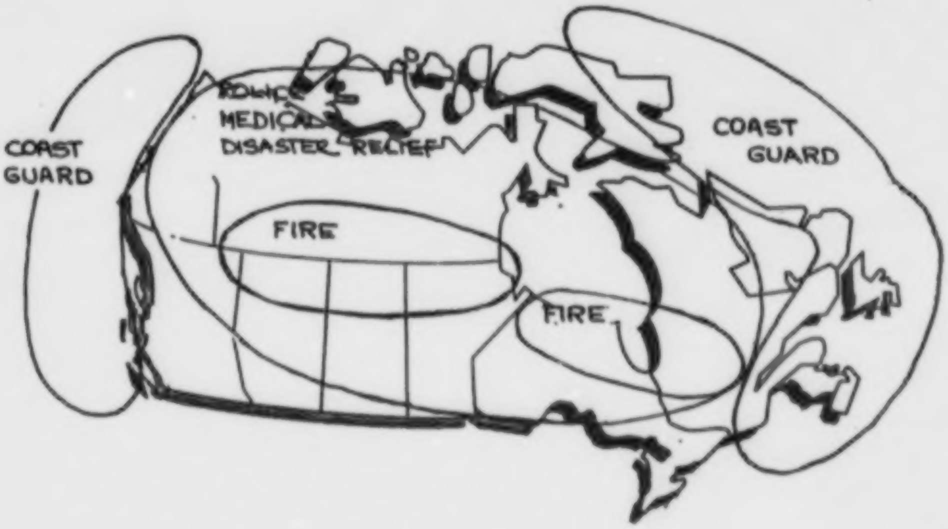
CTR has been identified as a potentially beneficial technology in the areas of forest fire fighting, disaster relief and search and rescue, due to the ability of the aircraft to cover a wide area of territory, remain aloft for long periods of time, fly at the speed of turboprops, hover and perform precise vertical landings and take-offs. Specific missions in this field would include command and control of operations, direct intervention, transport of high-priority personnel, and patrol and ambulance functions. In Canada, most of these activities fall under provincial jurisdiction and, therefore, decisions concerning the eventual use of tiltrotors will likely be made at that level.

At this point it is not possible to estimate the extent of this CTR application in Canada other than to observe that the large land areas involved for individual provinces might well make tiltrotors ultimately preferable to helicopters for many of these missions. The CTR vehicle configuration most suitable for this sector would seem to be the 8-passenger CTR-800. For some specific emergency missions involving the transportation of relatively large volumes of passengers in a short period of time, a minimum modification CTR-22 series would seem to be more appropriate.

Maritime and Border Patrol

The same characteristics which render CTR attractive as a support vehicle for emergency intervention and resource development favour its use for maritime and border patrol missions. This is hardly surprising since the latter share many requirements with the military missions for which the V-22 Osprey was originally developed. In Canada, this is the responsibility of the federal government. Given the current and expected future priorities of the Canadian government, the specific patrol tasks most likely to benefit from CTR would seem to be surveillance and intervention related to fishing rights, environmental incidents (e.g. tanker spills, etc.) and drug interdiction.

FIGURE 43
CANADIAN PUBLIC SERVICE TILTROTOR MARKETS



7.2.4 Corporate / Executive Air Service

The potential for application of CTR technology in the corporate/executive market is substantial. The 1987 NASA/Bell-Boeing **Missions and Applications Study** estimated that some 650 units will be required by the year 2000 to satisfy worldwide demand. In fact, according to the authors of the above-mentioned study, this sector represents the second largest single market after that of commercial air passenger service.

What makes CTR attractive to the corporate/executive market are the same performance characteristics of the vehicle mentioned previously in this report. The key factors favoring the choice of CTR for corporate use are related to overall costs to the companies (including the value of time), efficiency, operational flexibility and security.

Primary use of aircraft by corporations would fall into the following categories:

- executive transport
- transport of experts and critical skilled personnel
- high-value equipment and information movement
- public relation use.

The smaller versions of CTR vehicles with seating capacities of 6 to 15 offer benefits highly appreciated by corporate users:

- mission flexibility
- speed
- efficiency
- security.

Pressurization of the CTR cabin would be essential for corporate use; therefore, it would be the second generation of CTR vehicles which would be appropriate to serve this market. In order to maximize the potential of CTR use by corporate clients, the new vehicles will have to be certified for operation in and out of the numerous private heliports currently in use by corporate helicopter fleets. Without detailed market analysis, it is impossible to provide any greater detail on the specific implications of the use of CTR by Canadian corporations.

7.2.5 Air Cargo / Package Express Services

Express package services represent the fastest growing sector of the air transport industry. Introduction of CTR technology into this market provides an opportunity to reduce the overall door-to-door time for delivery and improve the efficiency of operations.

The primary advantage of CTR utilization in this market lies in its capability to deliver goods by air faster and closer to their final destinations than under the current system. In order to take advantage of CTR services in this market, the operator would benefit from the existence of strategically located vertiports, easily accessible by road during night hours. Preliminary studies indicate that the CTR noise signature is such that the possibility of night operations is genuine, although this may well be a constraint in some noise-sensitive portions of urban and suburban areas.

The CTR market potential for cargo/package express in Canada seems to be limited to a few inter-city markets parallel to those identified as possible markets for commercial passenger service. It seems to be reasonable to assume that the development of this CTR market could start as an extension of CTR air passenger express/package services in the U.S. Using the aircraft for passenger service during the day and for package express service during the night would improve the total daily utilization of the vehicle. Dedicated aircraft would likely be introduced once the service is well established and proven.

APPENDIX 1
CANADAIR CL-84

CL-84 TILT WING APPLICATIONS

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ABSTRACT

A review of tilt wing characteristics and flight test experience with the Canadair CL-84 prototype is presented. Included are results on handling qualities, performance, vibration, noise and downwash characteristics.

The paper presents results of design studies on three tilt wing variants based on the prototype configuration. These are: a multi-mission variant for light military roles such as utility transport, close support, and search and rescue; a higher performance close support aircraft; and a short haul commercial transport.

Alternate tilt wing design configurations providing higher wing loading for cruise and cyclic pitch control for hovering and transition are discussed. The effect of advanced technology in the propeller, engine and structures field on the tilt wing transport payload is assessed.

FIG. 1 CL-84 PROTOTYPE IN HOVERING FLIGHT

INTRODUCTION

The CL-84 tilt wing V/STOL prototype was developed by Canadair as a shared cost program with the Department of Industry of the Canadian Government. The contract was awarded in August 1963 and the first flight took place in May 1965. Fig. 1 shows the prototype in hovering flight and a description of the aircraft and its development history is given in Ref. 1. The prototype was lost in an accident on September 12, 1967 which was attributed to an uncontrollable yawing moment that developed in conventional flights at 130 knots due to a malfunction in the control system to the propellers. The pilot and test observer ejected successfully.

In February 1968 an order was received from the Canadian Government for three follow-on CL-84-1 aircraft for military evaluation by the Canadian Armed Forces. These aircraft are similar to the prototype but incorporate many detail improvements and have added operational capability. The first aircraft will be on test status early next year, and all three will be engaged in military evaluation by the latter half of 1970. This will encompass roles such as utility transport, helicopter escort, close support, reconnaissance, search and rescue and anti-submarine warfare.

TILT WING CHARACTERISTICS

The tilt wing V/STOL aircraft obtains vertical lift from rigid "airplane" type propellers mounted on the wing which tilts from a vertical attitude for hovering to a horizontal attitude for cruise. The same propellers then provide the propulsion. Several configurations have been used for tilt wing aircraft, namely: the two propeller single wing type characterized by the Hiller X-18, the Vertol VZ-2 and the Canadair CL-84; the four propeller single wing type characterized by the LTV, XC-142A; and the four propeller tandem wing VC-400 being developed in Germany by VFW.

The propeller disc loading for this class of aircraft can vary between approximately 20 to 80 pounds per square foot. This places it in a range between the helicopter on one hand and the fan or jet lift types on the other hand, and indicates an operationally more flexible vehicle well suited for applications where range, endurance, high speed and a moderate amount of hovering are required.

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* Senior Project Engineer, CL-84

In hovering flight the moderate disc loading of the tilt wing contributes to operational characteristics such as good hovering efficiency, downwash low enough for operation from unprepared surfaces, low noise levels and no exhaust temperature problems.

In flight at intermediate tilt angles, between hovering and cruise, the tilt wing benefits from the powerful lift augmentation on the wing at low speed produced by the propeller slipstream. This brings about a rapid reduction with speed in power required to sustain level flight as illustrated in Fig. 4. The large excess power is thus available to enhance low speed performance such as short take-off, acceleration, rate of climb and turning capability. On the other hand the ability to readily tilt the resultant of the thrust and lift vectors aft enables high deceleration and rates of descent to be achieved at low speed. The rapid reduction in power with speed also results in good fuel economy for loiter and shrinks the "Dead Man's Curve". The latter is important because, unlike the helicopter, the tilt wing has no autorotative capability.

In cruise or high speed flight, with the wing locked down, the tilt wing exhibits the same general characteristics as conventional turbo prop aircraft with respect to propulsive efficiency, lift/drag ratio and handling qualities. Good cruise performance over a wide range of speed and altitude is obtained by using the combination of a propeller for thrust and a wing for lift. The compromises in propeller efficiency and lift/drag ratio for most applications can be surprisingly small in a well designed tilt wing aircraft.

Unlike stowed rotor or other convertiplane concepts, the tilt wing makes use of the same main components for vertical lift in hovering and propulsion in cruise. This avoids the weight, cost and complexity of providing separate systems, and for transferring the power from one system for hovering to another for cruise. The pilot's work load is also less with the tilt wing as he does not have to concern himself with changing over from one system to another during a critical phase of the flight. The transition from one mode of flight to the other is smooth, continuous and rapid without abrupt changes in flight characteristics.

The ability to tilt the lifting system independently of the rest of the aircraft allows the pilot to maintain the fuselage level during short take-offs, climbs, low speed flight, descents and short landing. This is particularly important in short take-offs, where the full performance potential of some deflected slipstream aircraft could not be utilized because of pilot disorientation at the high nose-up angles.

PROTYTYPE FLIGHT TESTS

The CL-84 prototype flight tests extended over a period of more than two years with 305 flights totaling 145 hours. In addition to the two Canadair test pilots, fourteen other pilots representing the Canadian Armed Forces, Royal Air Force, US Airforce, Army and Navy, NASA and the NAE flew the aircraft and commented on its characteristics. The following summarizes the handling qualities, performance and other characteristics which are relevant to the variants and missions discussed in this paper.

Handling Qualities

Hovering Flight. For vertical take-offs the aircraft was headed into wind with wing tilt adjusted to maintain position. The lift-off was smooth and positive with little control activity required to maintain a level attitude and position over the ground. Vertical landings were accomplished by reducing power from stabilized hover out of ground effect and allowing the aircraft to descend until the positive ground effect at about 2 to 5 feet wheel height arrested the descent. Setting the aircraft smoothly on the ground from that point required a little pilot familiarization because of random disturbances in ground effect, but the technique was easily mastered.

Longitudinal control response and sensitivity by the tail propeller were rated good with the Stability Augmentation System (SAS) on. With the "attitude hold" mode of the pitch SAS disengaged the response was better, but with all pitch SAS off there was a tendency for pitch divergence which increased the pilot's work load. For forward and aft translation the pilots preferred to use wing tilt while holding the fuselage level. This was smoother, easier and more natural than tilting the whole aircraft.

Lateral control power by means of differential pitch on the main propellers was satisfactory, but most pilots felt that increased sensitivity with the SAS on would be more desirable. This is being provided in the follow-on aircraft. With roll SAS off the control response improved, but oscillations were present which increased the pilot effort. Lateral translations, with speed controlled by bank angle, were easy to accomplish.

Directional control by means of the flap-ailerons in the propeller slipstream was judged marginal by most pilots with yaw SAS on, particularly when turning the aircraft out of wind. With the yaw SAS off directional control was satisfactory and most pilots preferred to operate the aircraft in this way.

The flight testing indicated that a means of attenuating the SAS signal so that it does not oppose pilot input would be desirable about all axes. As an interim measure a dual mode system, which allows the pilot to select either a maneuvering or stabilized flight mode, is being provided in the follow-on aircraft.

Height control by means of the conventional airplane type power lever was easily mastered, even by helicopter pilots. The height control system provided good response and sensitivity although height damping may be desirable for IFR operations. A thrust-to-weight ratio of 1.02 was adequate for take-off, 1.05 for all normal hovering maneuvers and 1.07 for landing under the conditions tested.

The vertical take-off, landing and hovering characteristics were evaluated in winds up to 40 mph. The pilot's work load incrased with increasing gustiness, but no particular problems were encountered.

Transition Flight. The conversion from hover to cruise flight, up to the maximum rate, was smooth and easily accomplished. No significant trim changes were apparent as a result of the programmed flap, horizontal tail and tail propeller blade angle with wing tilt. The reconversion from cruise to hover was also easy if performed at moderate rates of deceleration, but became more difficult at the maximum rates. This was to a large part due to hardware deficiencies in the wing tilt system, and thrust control system at the low power levels. Modifications to these systems in the follow-on aircraft are expected to result in improvements in this area.

Flight at intermediate tilt angles presented no difficulty. Desired speed was trimmed by means of wing tilt rather than stick position, with the latter being used to maintain fuselage level. Fig. 2 shows trimmed wing tilt angle versus speed, and also indicates the excellent agreement between estimates and flight test data. Control response and sensitivity about all axes were generally rated as good, and maneuvers, including tight turns up to 2g load factor, were performed. Some improvement in attitude stability at the lower wing tilt angles may be required for IFR operation.

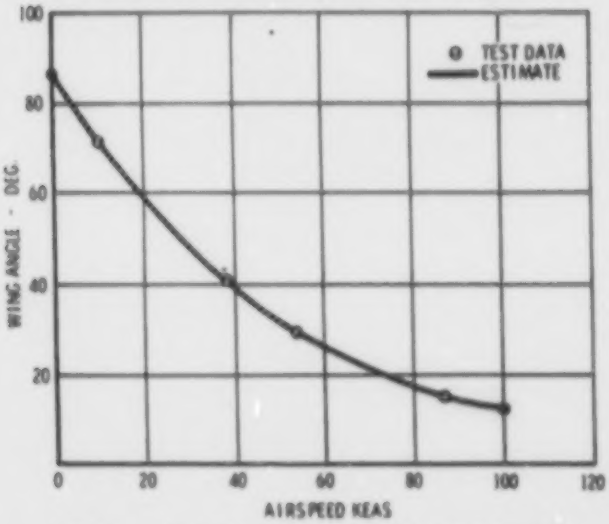


FIG. 2 TRIMMED WING ANGLE VS SPEED - PROTOTYPE

The triple fin configuration provided positive directional stability at all wing angles, and the lateral-directional characteristics met the proposed AGARD requirements. Control cross-coupling was small as a result of the control system programming. The dynamic stability about all axes with SAS on was satisfactory, with the motions following a control pulse either deadbeat or damped out in little over one cycle.

As in hovering flight initial control response was better with SAS off but the instabilities present, particularly in pitch, increased the pilot's work load.

Short Take-Off and Landing. Short take-offs and landings were performed at all wing tilt angles between 15 and 90 degrees. The technique for take-off was to hold the fuselage approximately level during the ground roll and climb-out. All pilots found this a natural and comfortable procedure which was easy to perform. Similarly for landing the fuselage was held level during the approach at a descent angle of about 10 degrees and a stabilized rate of descent of about 700 feet per minute. Power was applied just prior to touchdown to reduce the rate of descent. There was a mild nose-down trim change in ground effect, but touchdown was firm and ground effect did not cause deterioration in handling qualities at any tilt angle.

The boundary for buffet onset during descents was investigated and the results are shown in Fig. 3. Buffet was mild, there was no handling qualities problem and recovery was immediate on application of power. Although this boundary is generally satisfactory, it is less than estimated, and further wind tunnel testing is planned to improve on it.

Cruise Flight. The flight envelope up to 300 knots TAS and 2g load factor was explored. The maximum level flight speed attained was 265 knots TAS at 8000 feet and the maximum load factor was 3g at 188 knots.

Less attention was devoted to handling qualities in the cruise flight regime compared to the hovering and transition regimes. These were generally satisfactory, although there was a problem with insufficient elevator effectiveness at low speed, and most pilots reported weak directional stability at small sideslip angles. The main pilot complaints in cruise however were related to detail hardware deficiences of the prototype control system. These included

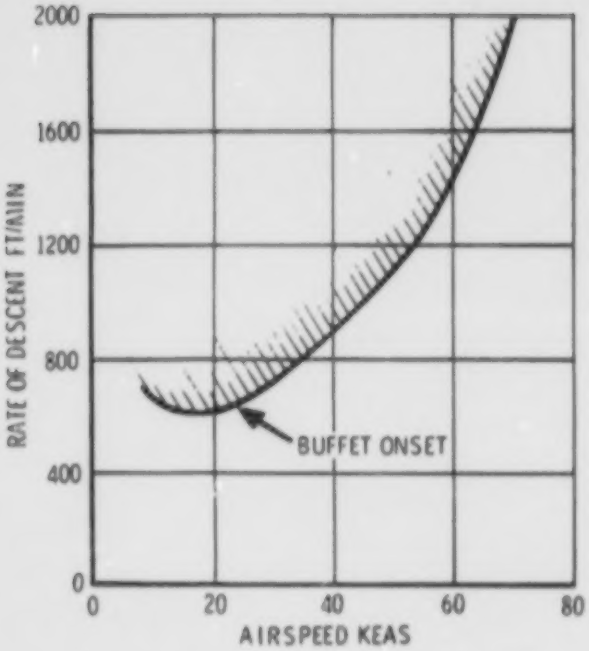


FIG. 3 RATE OF DESCENT VS SPEED - PROTOTYPE

lack of artificial feel, low trim rates combined with hysterisis and friction in the control system which made trimming the aircraft difficult, inadequate propeller governing, and small spurious control inputs due to backlash or deformations. Modifications to the control systems on the follow-on aircraft should eliminate these problems.

Performance

Power required for level flight was measured over the range of airspeed from hover to the maximum attained. Figure 4 shows flight test data for the hover and transition regime compared with estimates based on wind tunnel and model propeller tests. There was a deficiency at hover amounting to about 4% of thrust, which is apparently due to an adverse airframe-propeller interference, and model testing is underway in an attempt to resolve this. However the thrust-to-weight ratio initially assumed to meet AGARD requirements for thrust margin and control power was 1.07, which, as previously indicated, was found to be conservative by about 2% for hovering. The net thrust deficiency was therefore abount 2%, which is still significant as far as hovering payload is concerned. However experimental work on propeller static thrust at Canadair has evolved a new blade design that more than makes up this deficiency.

Above 40 knots the measured power required becomes equal to that estimated at the corresponding RPM, indicating somewhat better aerodynamic efficiency than predicted from the wind tunnel tests. Although flight tests to confirm the variation of power with speed at optimum propeller RPM were not completed, the existing test data confirms the estimated transition and STOL performance.

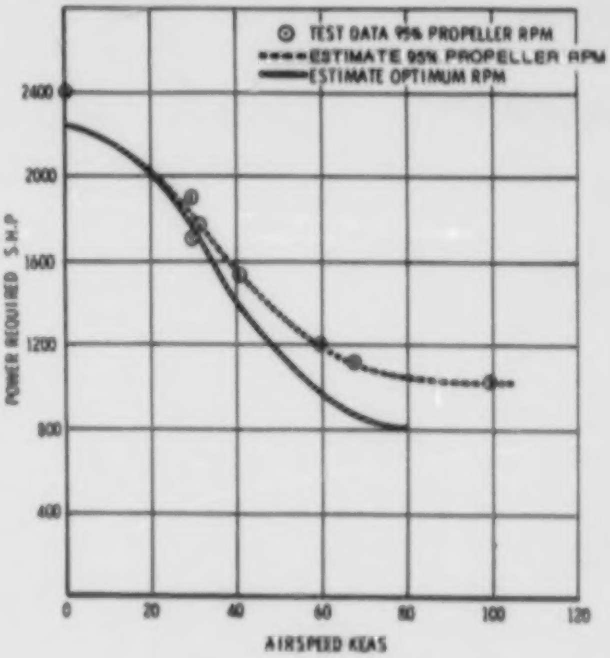


FIG. 4 POWER REQUIRED VS SPEED - PROTOTYPE

In cruise flight the aircraft drag was higher than estimated. This was due to the usual prototype problems such as gaps, leaks, protuberances and instrumentation. The sources of major drag increase have been identified and measures taken to eliminate them in the follow-on aircraft.

Vibration

The CL-84 prototype vibration levels were normally very low, particularly in cruise flight at reduced power and propeller speed, and pilot comment under these conditions was very favorable. There was an increase in vibration during hover and transition due to the higher power, but this was well within limits. However careful static and aerodynamic balancing of the propellers, using special procedures developed in the course of the test program, was necessary in order to achieve this, and relatively small unbalance produced large vibrations at the "once per propeller revolution" frequency.

No resonances were identified in the propellers or transmission system components over the full RPM range for all flight conditions, and no operating restrictions were necessary. Fig. 5 shows bands of vibration level versus RPM measured on the propeller and other gearboxes of the transmission system.

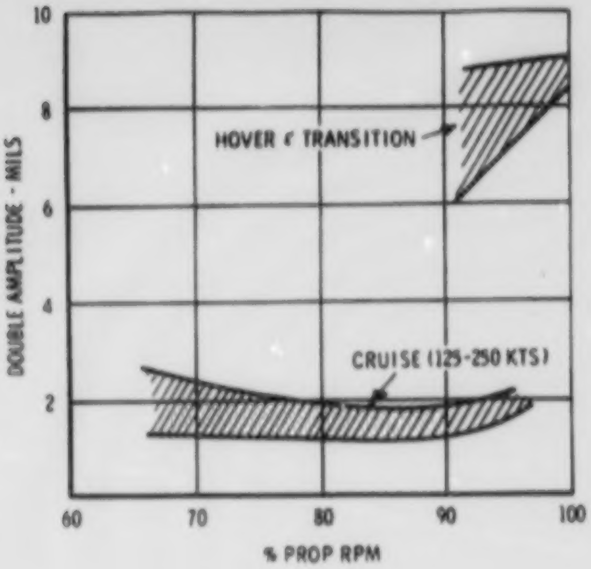


FIG. 5 GEAR BOX VIBRATION LEVELS - PROTOTYPE

A considerable amount of vibratory stress data was also collected on the main and tail propellers, gearboxes and attachment structure. Typical results are shown in Fig. 6, which indicates variation of propeller blade shank vibratory bending stress with airspeed and tilt angle

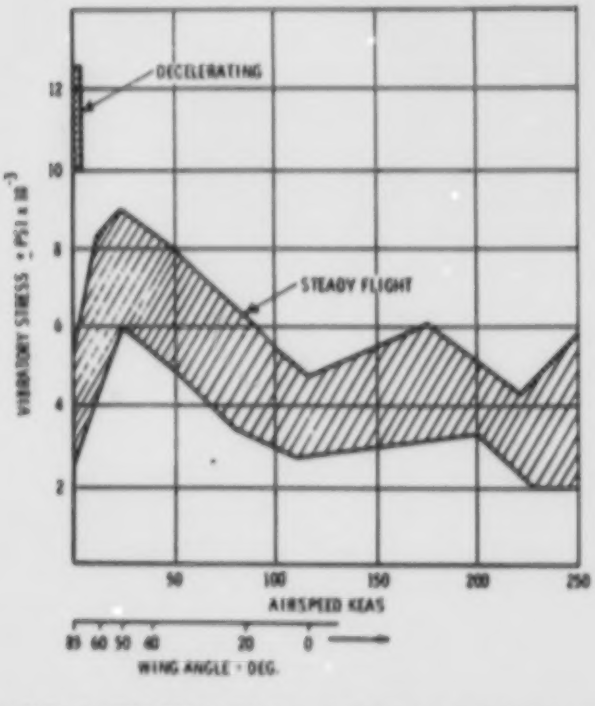


FIG. 6 PROPELLER BLADE SHANK VIBRATORY BENDING STRESSES - PROTOTYPE

for steady flight condition. The highest stress levels shown occur at very low speed during deceleration immediately prior to coming to a hover, and are probably due to some form of recirculation. However these are well within the design allowables and of about the same magnitude as extrapolated for the maximum design case in conventional flight.

Fatigue problems due to vibratory stresses were discovered in the tail propeller hub during the ground test phase, in the main propeller control unit late in the flight test program, and in the engine exhaust system. Except for the last item, these were satisfactorily corrected during the test program and the prototype propellers and transmission system components did not have any life limitations due to fatigue. A modification to overcome the enigine problem is being incorporated in the follow-on aircraft.

Noise

External noise measurements were taken with the aircraft hovering at a height of 50 feet, and the sound pressure levels are shown in Fig. 7. No external measurements were taken in cruise flight, but the aircraft impressed observers on the ground with its quietness.

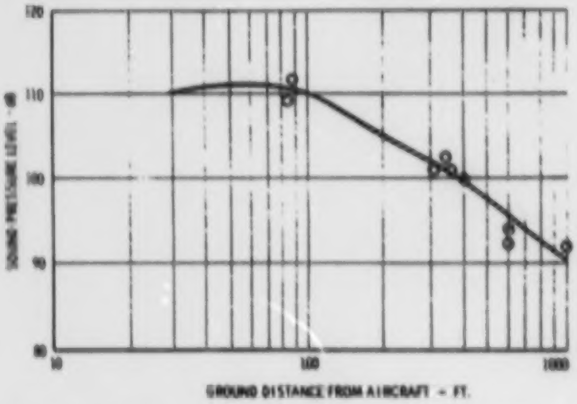


FIG. 7 EXTERNAL NOISE LEVELS IN HOVER - PROTOTYPE

Internal noise was also measured in hover, transition and cruise, and in only a few cases the limits for unprotected ears were exceeded slightly, even though no soundproofing was used on the prototype.

Downwash

Probably no other characteristic of V/STOL aircraft has aroused more controversy than the question of downwash. The limited operational suitability testing carried out with the prototype was directed primarily towards obtaining answers to these questions.

The prototype testing included simulated rescues with live subjects from land and water, and of a dummy through 60 foot trees. In addition the aircraft was hovered 20 feet above water and 5 feet above trees, and on many occasions in close proximity to unprotected personnel. No problems were encountered in any of the above operations. It should also be mentioned that both the LTV XC-142A tilt wing and the Ryan XV-5A fan-in-wing aircraft underwent more extensive testing of this nature and again, as far as is known, no serious problems were encountered. Downwash velocity measurements were also made with the CL-84 prototype and the data is given in Ref. 2.

It is difficult to make meaningful quantitative comparisons of downwash between different V/STOL concepts. A general observation based on several comparative tests on tilt wing aircraft and helicopters of equal gross weight is that, when close to the ground, the tilt wing generates a more concentrated, higher velocity region directly beneath the aircraft than does the helicopter, but at approximately a wing span or rotor diameter from the center there is very little noticeable difference between the two. Further away, the tilt wing produces less disturbance than the helicopter. It thus appears that different operational techniques will have to be developed for each type, but so far the evidence indicates that the tilt wing should be able to perform all missions presently carried out by the helicopter. Further, more extensive testing is required to develop the best techniques for each mission, and the forthcoming evaluations of the follow-on CL-84-1 aircraft by the Canadian Armed Forces will generate much useful data on this subject for a variety of operational roles and conditions.

OPERATIONAL VARIANTS

Variants of the CL-84 prototype have been investigated for a wide range of operational roles. Of these, three aircraft, representative of the complete spectrum have been selected as examples of the broad application of the tilt wing concept. Leading particulars of these aircraft, which will be described in this paper, are given in Table 1.

Variant A is a direct derivative of the prototype for a light utility, multi-mission role. Variant B is a larger, higher performance armed version for close air support of ground troops, and Variant C is a considerably larger aircraft for short-haul commercial transport. All these aircraft are similar in geometry and close to the prototype in wing loading and propeller disc loading. Their handling qualities and other flight characteristics should therefore also be similar.

Variant A

This version is a logical first stage growth of the evaluation aircraft presently under construction for the Canadian Armed Forces. It makes use of essentially the same systems and airframe but has uprated engines to increase the hot day power by about 25%. The engines are torque limited under standard conditions to avoid dynamic component development. The only significant external change is an increased cabin length to provide a volume of 280 cubic feet and room for 16 wall type troop seats.

The size, layout and performance of this aircraft appear ideally suited for a wide variety of light military roles, such as utility transport, close support, reconnaissance and search and rescue. This multi-mission capability with the same aircraft should greatly enhance its cost effectiveness, specially for a small self-contained mobile force.

TABLE 1
TILT WING APPLICATIONS

VARIANT	A	B	C
Application	Multi-Mission Light Utility	Close Air Support	Commercial Transport
Design Gross Weight Lb.	13,200	22,000	52,600
Engines No.	2	2	4
Rated SHP	1,800	4,990	4,800
Hover Design Point	SL 95°F	6000 Ft 95°F	SL 95°F
No. Engines Operating	2	2	3
Prop. Disc Loading Lb/Sq Ft	38	44	38
Wing Loading Lb/Sq Ft	56	65	56
Operating Wt Empty Lb	9,025	14,050	34,900
VTOL Payload Lb	2,575	4,000	13,600
Range NM	300	400	175
Cruise Speed Kts	250	370	350
Max Speed Kts	290	420	-
Wt Empty/Gross Wt	.69	.67	.66

Figure 8 shows typical interior arrangements for the above roles. In the transport role the most effective employment would be a short take-off at the base, wherever possible, to utilize the overload capability with a very short ground run. A vertical landing can be made at the destination after sufficient fuel is used up. In a mission of this nature 2000 pounds of cargo can be carried over a radius of 240 nautical miles.

In the air rescue role, the combination of high speed and hovering capability at the destination are of vital importance. On a typical rescue mission the aircraft can cruise out 225 nautical miles at 280 knots, pick up 4 men while hovering for 20 minutes and return to base.

For close air support and reconnaissance, emphasis would be on the ability to fly nap-of-the-earth, loiter economically and quietly at low speed and, where necessary, make use of the high dash speed for survivability. Ref. 2 describes the agility

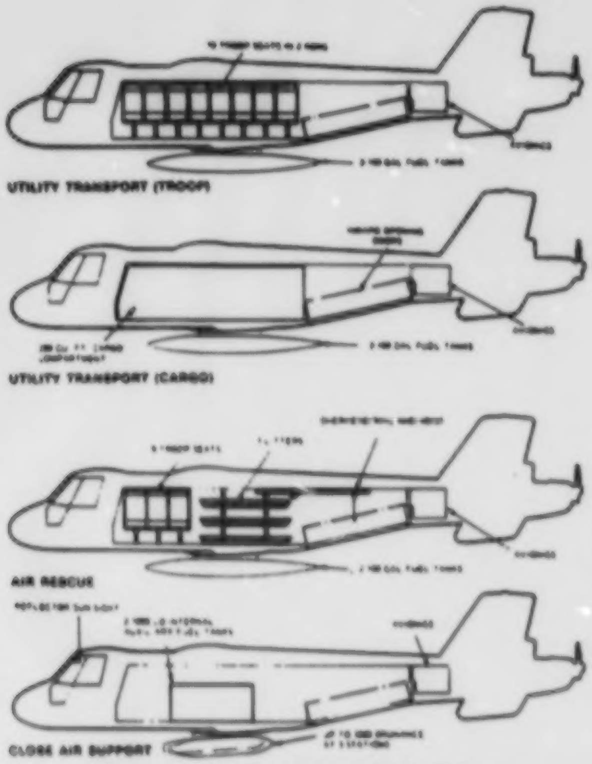

UTILITY TRANSPORT (TROOP)
UTILITY TRANSPORT (CARGO)
AIR RESCUE
CLOSE AIR SUPPORT

FIG. 8 MULTI MISSION LAYOUTS - VARIANT A

and other characteristics of this aircraft in the role of detecting and attacking small, well concealed targets in close support of ground troops. For a close support mission, the aircraft can cruise out 100 nautical miles, loiter on station for 2 hours, deliver 2000 pounds of ordnance and return to base.

Another important consideration, particularly in the reconnaissance role, is the aircrafts' detectability from the ground. Fig. 9 shows the estimated low noise levels at minimum power and propeller speed versus height above ground.

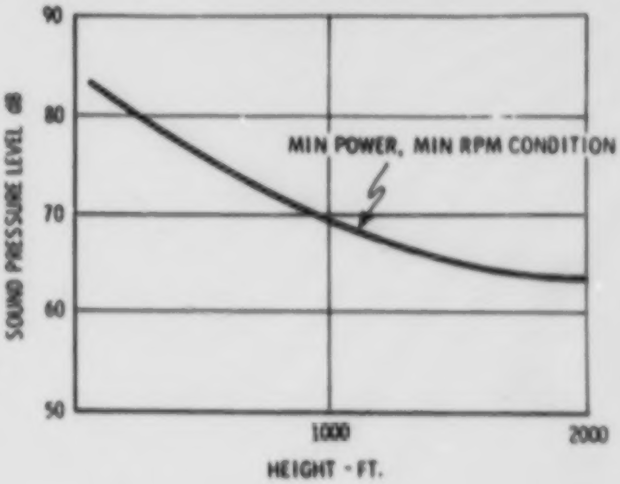


FIG. 9 ESTIMATED NOISE LEVELS ON GROUND - VARIANT A

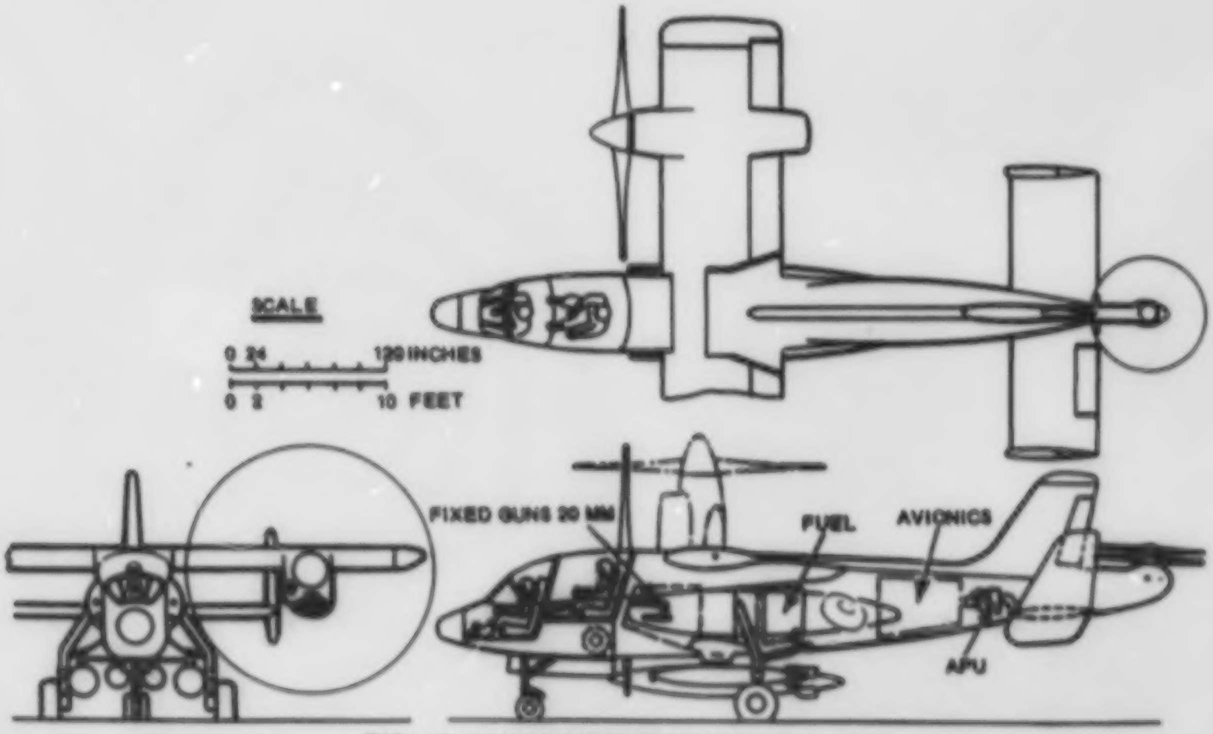

SCALE
0 24 120 INCHES
0 2 10 FEET
FIXED GUNS 20 MM
FUEL
AVIONICS
APU

FIG. 10 CLOSE SUPPORT VARIANT

With the installation of fuel tanks in the fuselage the aircraft becomes self deployable with a still air ferry range of 2300 nautical miles.

Variant B

Where a higher level of performance for the close support role than available with the previous version is required, the multi-mission concept involves more compromise, and a higher degree of specialization may be more cost effective.

Variant B, shown in Fig. 10, is typical of the more specialized types that have been studied. This aircraft is designed to hover under much more severe ambient conditions, carry a bigger payload, and have a considerably higher speed than the previous light close support version. It is powered by two growth General Electric T64 or Lycoming T-55 engines and accommodates a pilot and co-pilot/gunner seated in tandem in a minimum cross section fuselage. Full military equipment is carried, including armor, self-sealing fuel tanks, fixed 20 mm guns and external stores on a small stub-wing. The installation of flexible turret mounted weapons aimed by the co-pilot has also been investigated as a means of enhancing the effectiveness of the total system. In a typical mission the aircraft can cruise out 150 nautical miles at 350 knots, loiter for 2 hours, deliver 4000 pounds of ordnance and return to base. The maximum dash speed in the clean configuration is 420 knots.

Because of the requirement to hover at 6000 feet and 95°F the installed power is high, and therefore under more average conditions the maneuverability and agility in low speed flight are enhanced. Fig. 11 shows rate of climb and descent, Fig. 12 the sustained load factor that can be held in level turns versus speed, and Fig. 13 the acceleration and deceleration performance versus speed for standard conditions at the combat weight of 20,000 pounds. The above parameters can be illustrated in a more meaningful manner if one considers the problem of turning around in minimum time and distance after attacking a target, in order to deliver a second attack. The time and distance for this type of turn-around maneuver is shown in Fig. 14 versus initial speed. This data has been obtained by simulation and includes allowances for turn entry and pilot reactions.

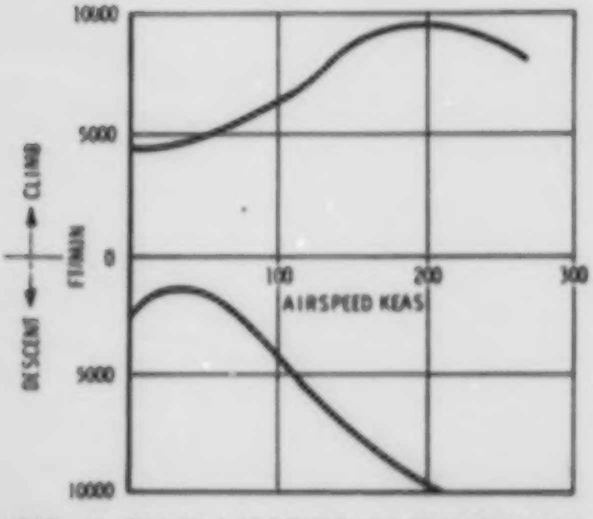


FIG. 11 CLIMB AND DESCENT PERFORMANCE - VARIANT B

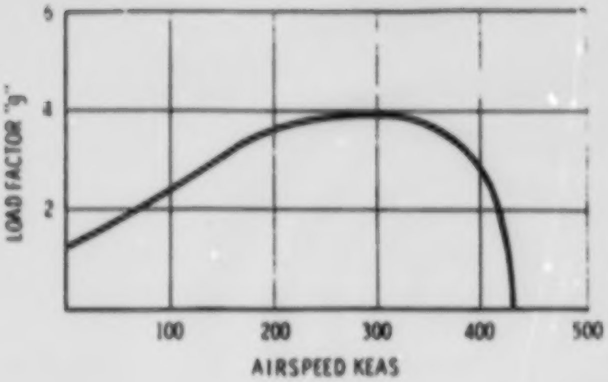


FIG. 12 SUSTAINED LOAD FACTOR - VARIANT B

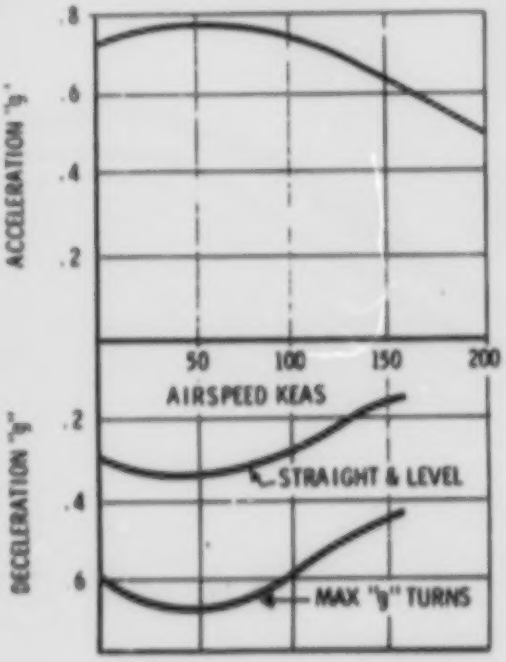


FIG. 13 ACCELERATION AND DECELERATION - VARIANT B

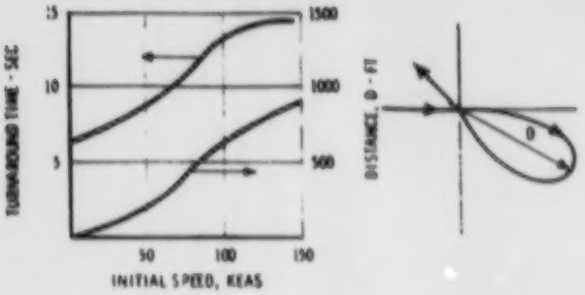


FIG. 14 TURNAROUND MANEUVER - VARIANT B

The unique agility described above, combined with a maximum speed of over 400 knots and the VTOL capability, introduces a new flexibility to air support in close proximity to ground troops, and invites a comparison of overall effectiveness with supersonic aircraft presently used for this purpose.

Search and rescue and utility transport variants based on the dynamic components of this aircraft have also been studied, and again these show important performance advantages over helicopters and fixed wing aircraft currently in use.

Variant C

In order to examine the tilt wing concept in larger size aircraft, a short haul inter-city V/STOL commercial passenger transport was selected as an example. This aircraft, shown in Fig. 15, is powered by four growth General Electric T64 or Lycoming T55 engines each rated at 4800 SHP, and carries 70 passengers in a pressurized cabin at the design range of 200 statute miles. It is designed for hover with three engines at the design gross weight of 52,600 pounds at an ambient temperature of 95°F at sea level. The aircraft is virtually

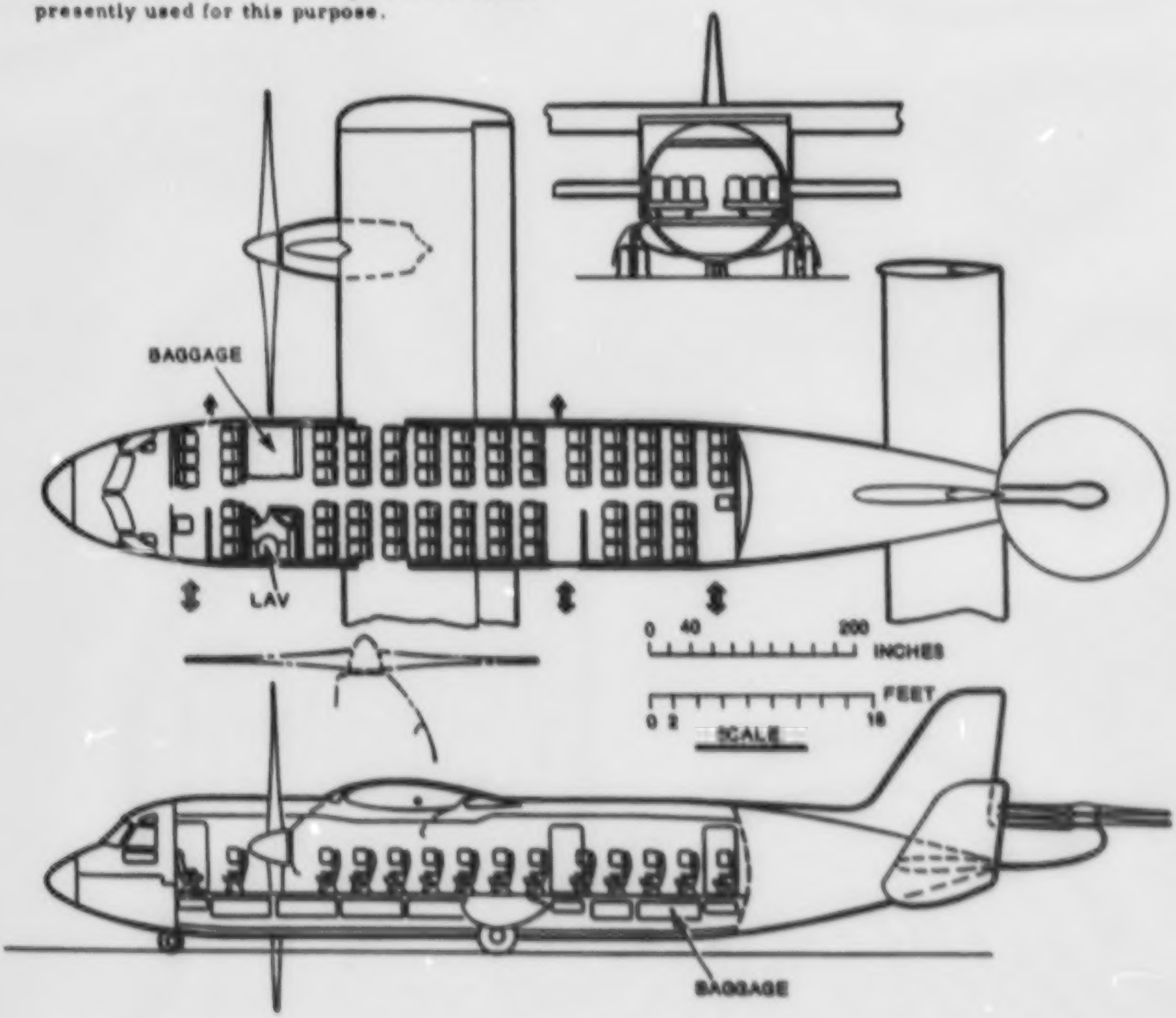


FIG. 15 COMMERCIAL TRANSPORT VARIANT

a scaled up version of the prototype with the same configuration, disc loading and wing loading. The aerodynamic development of the prototype is therefore directly applicable to this variant, in spite of its size.

The payload-range characteristics for this variant are given in Fig. 16 and the block times versus stage length in Fig. 17. The high acceleration, rate of climb, cruise speed and the steep descent angle contribute to low block times, even though current regulations in the United States which limit the speed to 250 knots EAS below 10,000 feet have been taken into consideration.

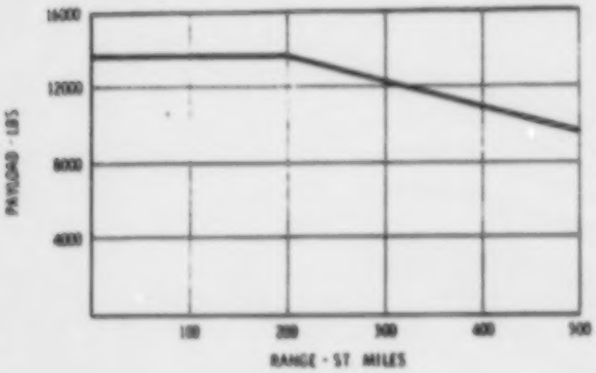


FIG. 16 PAYLOAD-RANGE - VARIANT C

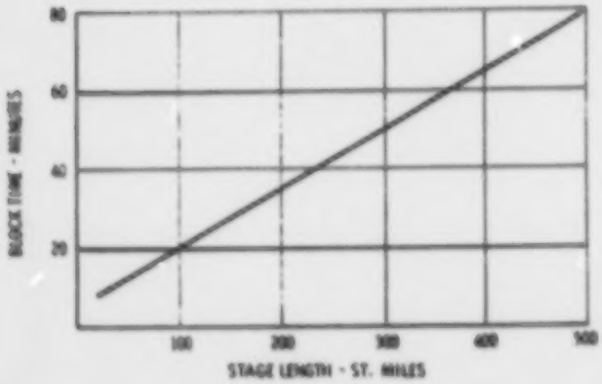


FIG. 17 BLOCK TIME VS STAGE LENGTH - VARIANT C

Of primary importance to an application of this nature is the safety aspect. The advantages of the very low approach speed and landing at zero speed are obvious, and should facilitate the development of blind landing systems. Although government airworthiness regulations for V/STOL aircraft are still being debated, the basic considerations assumed here, in addition to hovering with one engine out, are the ability to make a safe landing from cruise with one propeller feathered, or after complete loss of power.

Much concern has been expressed regarding safety problems with V/STOL aircraft because of their complexity, and indeed the record with prototypes has not been good. However the design requirements for propellers, drive trains and control systems to meet the necessary safety standards for aircraft of this type are now much more clearly identified, and work in this direction is proceeding.

Another very important consideration for civil V/STOL transports is public acceptance of the noise levels when operating from "Vertiports" located in city centers or other heavily populated areas. Fig. 18, shows estimated perceived noise level contours on the ground along the take-off path for the tilt wing aircraft. A vertical take-off, transition to 65 knots and climb at maximum rate was assumed. Other take-off profiles involving shorter exposure to somewhat higher noise levels are possible, but more information is required on criteria for public acceptance in this type of operation.

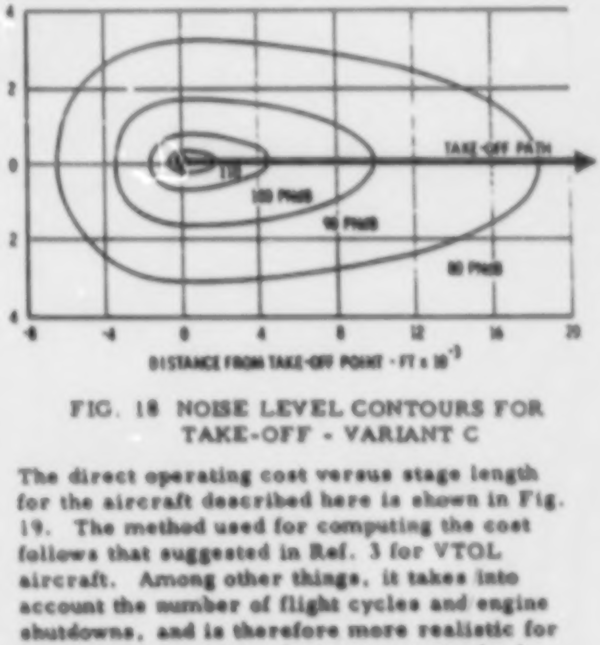


FIG. 18 NOISE LEVEL CONTOURS FOR TAKE-OFF - VARIANT C

The direct operating cost versus stage length for the aircraft described here is shown in Fig. 19. The method used for computing the cost follows that suggested in Ref. 3 for VTOL aircraft. Among other things, it takes into account the number of flight cycles and engine shutdowns, and is therefore more realistic for short-haul operations than present standard methods. It was assumed that the initial cost for the airframe is $4 million, the engines cost $400,000, and the annual utilisation is 2000 hours. The direct operating cost reaches a minimum of 1.85 cents per available seat statute mile at the design stage length of 200 statute miles. This is probably a good average stage length, however the operating costs are still attractive for distances as low as 50 miles and as high as 500 miles.

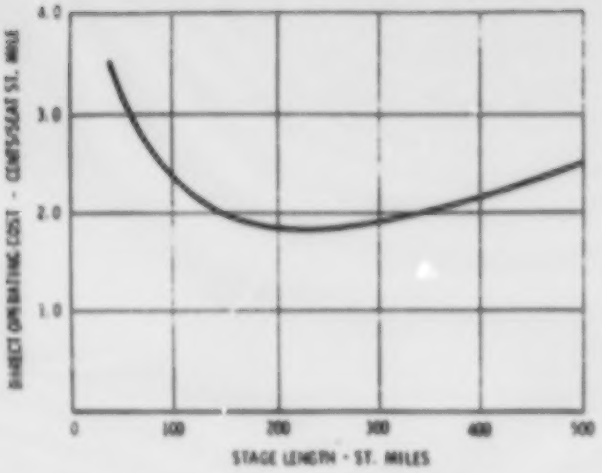


FIG. 19 DIRECT OPERATING COSTS - VARIANT C

The main competition for the tilt wing in short-haul passenger operation will be the advanced helicopter and the short range conventional jet transport. Studies have shown that the operating costs for the helicopter will be higher for stage lengths of more than about 25 miles, basically because of its lower cruise speed. On the other hand beyond stage lengths of about 500 miles the conventional jet transport becomes more economical and faster, even on an overall basis including ground transportation. Between these distances the tilt wing appears to be the most suitable aircraft. Its operating cost is about half that of advanced helicopters, and compared to conventional jet service, the tilt wing offers for the average traveller considerable overall saving in time and cost due to reduced ground transportation, without real sacrifice in block speeds. The heavy and growing concentration of people in the downtown city areas might provide a large potential market for a city-center to city-center service that will permit a traveller to leave his downtown office for a destination several hundred miles away, and return to this office the same day.

Many problems must still be overcome before a viable service of this type can become a reality, but it is believed that the combination of a high speed VTOL vehicle with advanced air traffic control, navigation and automatic flight control systems for operation under zero-zero conditions, could provide a solution to present day short haul transportation problems.

An aircraft of the type described here would also make a very effective V/STOL military transport. A new fuselage with rear loading, a more rugged, lower flotation landing gear and other changes of this nature would be required, but the dynamic components and other basic systems could be similar.

ALTERNATE CONFIGURATIONS

The CL-84 prototype, and the derivatives described in this paper, were designed on a conservative basis with respect to transition aerodynamics and control means. The wing area in the propeller slipstream is ample, and as a result sophisticated high lift systems were not required. A simple 10% chord leading edge Kruger flap and a 30% single slotted trailing edge flap were used.

For some applications a higher wing loading in cruise, than obtained by using the prototype wing - propeller proportions, may be advantageous from the drag and/or gust response aspects. This requires more elaborate flap systems than on the prototype in order to retain the same transition performance, and several such systems, as shown in Fig. 20 have been designed and tested in the wind tunnel. The weight, cost and complexity of these systems must be evaluated for each application, together with the advantages from the higher wing loading in cruise, in order to select the best combination.

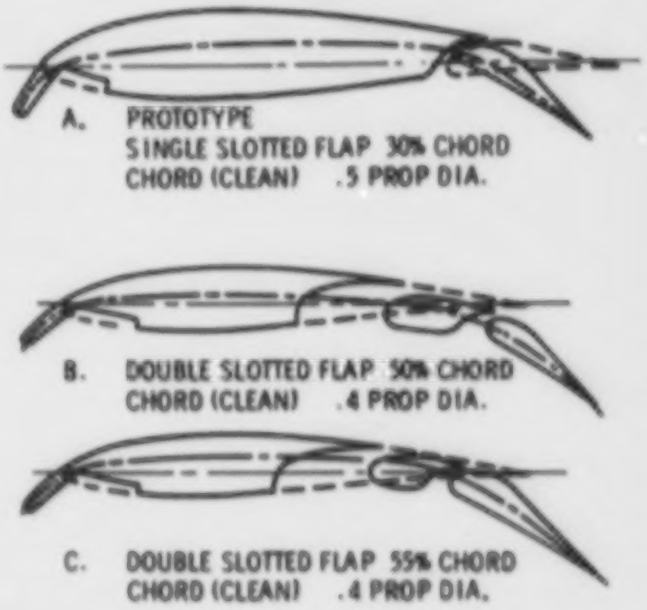

A. PROTOTYPE
SINGLE SLOTTED FLAP 30% CHORD
CHORD (CLEAN) .5 PROP DIA.
B. DOUBLE SLOTTED FLAP 50% CHORD
CHORD (CLEAN) .4 PROP DIA.
C. DOUBLE SLOTTED FLAP 55% CHORD
CHORD (CLEAN) .4 PROP DIA.

FIG. 20 HIGH LIFT SYSTEMS TESTED

Another alternate tilt wing configuration is the use of cyclic pitch on the main propellers for longitudinal control in hover and transition, in place of the tail propeller. This scheme was considered for the prototype, but the tail propeller approach was selected on the grounds that it provides a powerful, easily predicted control moment and avoids difficult mechanical and structural development problems on the main propeller. Potential propeller-wing interaction problems in transition are also reduced. However the potential advantages of reduced system complexity, cost and maintainability with cyclic pitch control are very attractive, and again a careful trade-off study is required for each specific application.

In order to obtain the necessary performance and aerodynamic data for such trade-offs, Canadair is presently conducting a model test program on the cyclic pitch propeller concept. Fig. 21 shows the model propeller and nacelle to be tested separately under static and forward speed conditions, and then mounted on the wing of a reflection plane model for overall wind tunnel tests.

FIG. 21 CYCLIC PITCH PROPELLER MODEL

Another interesting propeller development that should be considered is the variable camber concept developed by Hamilton Standard. For some applications, particularly where the disc loadings are towards the higher end of the range for tilt wing aircraft, the variable camber propeller offers advantages in hover payload, maximum speed and noise. These can become significant when the mission requires high speed, long range or a combination of both.

ADVANCED MATERIALS & ENGINE TECHNOLOGY

In the same way that the advent of the turbine engine made non-rotary wing V/STOL aircraft technically and economically feasible, the advanced materials and engine technology projected for the next decade will make them competitive with conventional aircraft on the basis of weight empty and payload to gross weight ratios.

The most important improvements in sight appear to be in the propeller and mechanical transmission systems, and Ref. 4 gives a picture of the potential gains in this area. These constitute, for the 1970-75 time period, a 40-50% improvement in propeller and gearbox weight, a 2-3% improvement in static thrust, a 5-7% improvement in installed cruise efficiency and a 6-10 db reduction in take-off noise.

Since the installed power in V/STOL aircraft is relatively high, major benefits will also accrue from advanced engine technology. A 30-40% improvement in weight and a 20-30% improvement in specific fuel consumption are being predicted for the 1975 time period. Studies on the application of new composite structural materials to V/STOL aircraft are still in the early stages, and the potential weight reductions in this case are at present more difficult to define. However it is quite clear that major improvements in weight will be achieved.

In order to project the net effect on payload of the potential advances in technology discussed above, a study was carried out on the tilt wing commercial transport variant described in this paper. For this study the gross weight, installed power, disc loading, wing loading, range and speed were held constant, while the payload (or number of passengers) and fuselage length to accommodate the payload were varied. Fig. 22 shows a comparison of major system and fuel weights and indicates approximately a 30 percent net increase in payload. A corresponding improvement in direct operating cost can be expected.

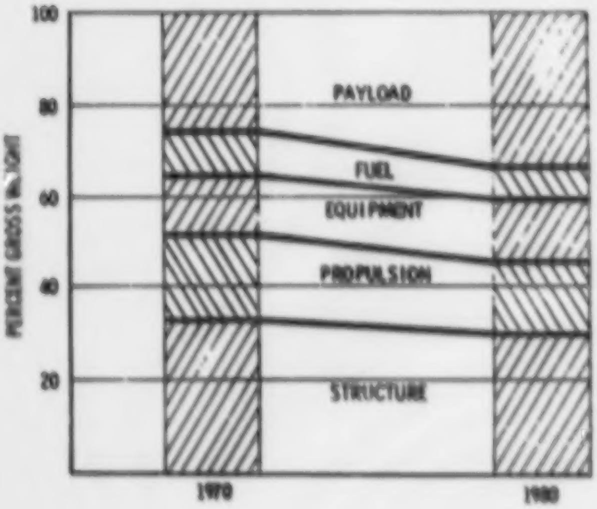


FIG. 22 ADVANCED TECHNOLOGY WEIGHT COMPARISON - VARIANT C

CONCLUDING REMARKS

Flight testing of the CL-84 tilt wing V/STOL prototype, together with design studies on variants up to over 50,000 pounds gross weight, have demonstrated the feasibility of this type for operational roles. The roles studied include utility transport, close air support, search and rescue and short-haul commercial transport operation. The tilt wing characteristics that contribute to effectiveness in these roles are the excellent STOL capability, low speed flight agility, high cruise speed, good hovering efficiency and economical operation.

Departures from the prototype configuration, that are being examined as potential improvements for some applications, provide higher wing loadings for cruise and cyclic pitch for longitudinal control in hover and low speed.

Advanced material and engine technology projected for the next decade will make important improvements to the tilt wing payload.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to all members of the Canadair and General Dynamics/Convair organizations whose efforts contributed to this paper.

LIST OF REFERENCES

1. Phillips, F.C., "The Canadair CL-84 Tilt-Wing V/STOL Program" Paper presented to the Rotorcraft Section, Royal Aeronautical Society, London, England, 24 April 1968.

2. Bernstein, S., "The Canadair CL-84 Tilt-Wing V/STOL Aircraft in Special Air Warfare Operations". AIAA Paper No. 66-780.

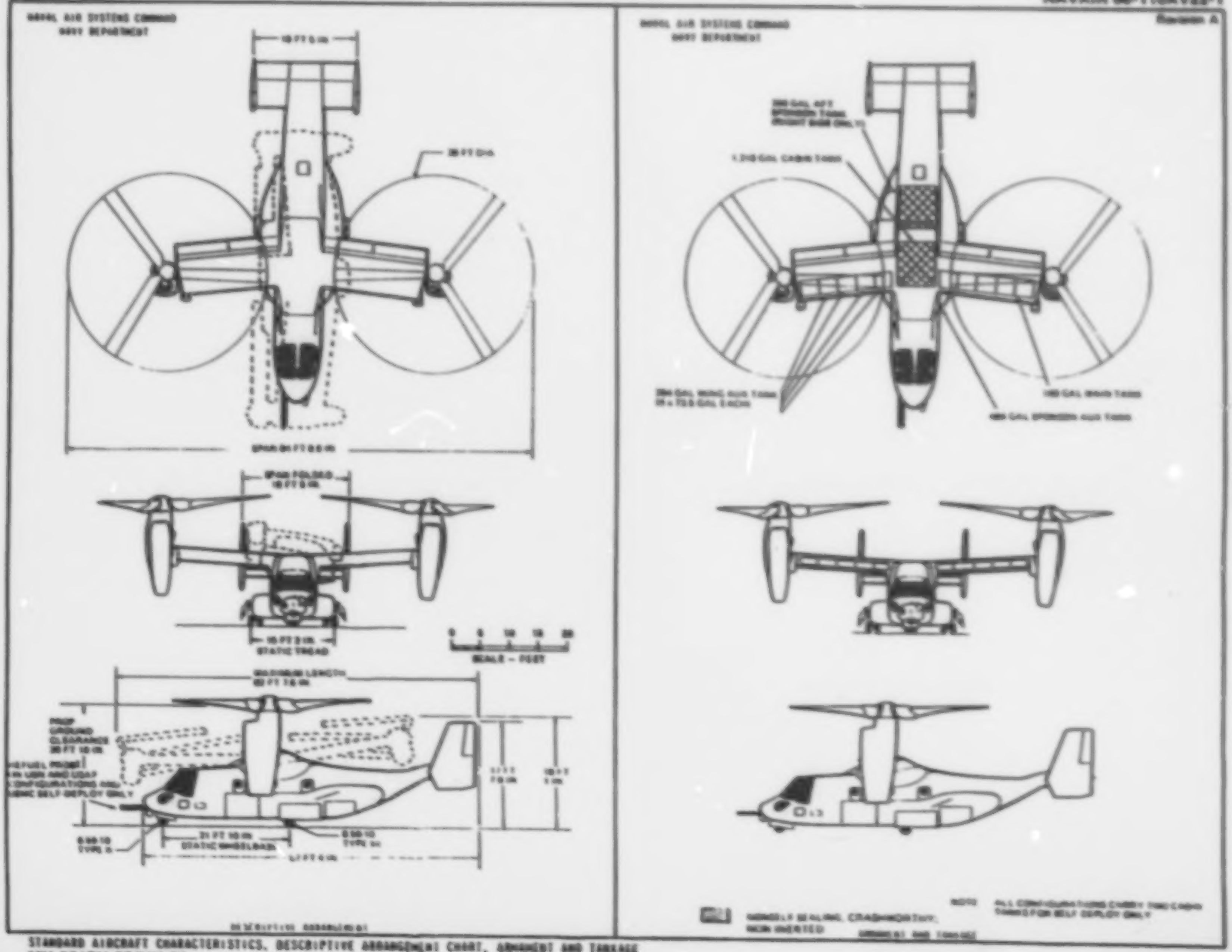
3. Stoessel, Robert F., and Gallagher, John E., "A Standard Method for Estimating VTOL Operating Expense (A More Realistic Approach)" AIAA Paper No. 67-828.

4. Rosen, George. "Next Generation V/STOL Propellers". SAE Paper No. 680281.

APPENDIX 2
AIRCRAFT CHARACTERISTICS

BELL-BOEING	MV-22 "OSPREY"
BELL-BOEING	CTR-22A/B
BELL-BOEING	CTR-22C
BELL-BOEING	CTR-22D
BELL-BOEING	CTR-800
BELL-BOEING	CTR-1900
BELL-BOEING	CTR-7500
EUROFAR	Baseline Configuration
ISHIDA	TW-68
MAGNUM T/R	MTR-201

BELL-BOEING MV-22 "OSPREY"


NAVAL AIR SYSTEMS COMMAND
NAVY DEPARTMENT
STATIC TREAD
SCALE – FEET
0 5 10 15 20
MAXIMUM LENGTH
PROP GROUND CLEARANCE
STATIC WHEELBASE
DESCRIPTIVE ARRANGEMENT
NAVAL AIR SYSTEMS COMMAND
NAVY DEPARTMENT
NOTE ALL CONFIGURATIONS CARRY TWO CABIN TANKS FOR SELF DEPLOY ONLY
SELF SEALING, CRASHWORTHY, NON INERTED
ARMAMENT AND TANKAGE

STANDARD AIRCRAFT CHARACTERISTICS, DESCRIPTIVE ARRANGEMENT CHART, ARMAMENT AND TANKAGE

MV-22/CV-22/HV-22

2

POWER PLANT

No. & Model:	2 T406-AD-400
Manufacturer:	Allison Gas Turbine Division
Engine Spec No.:	837 (Fourth Draft) 22 July 85
Type:	Turboshaft

RATINGS

	SHP	RPM	ALT
Maximum	6150*	15,000	Sea Level, 59°F
Intermediate	6150*	15,000	Sea Level, 59°F
Maximum Continuous	5890	15,000	Sea Level, 59°F
Transmission Limits:	3821**	12,376	Cruise rpm
	4300**	15,000	USMC
*Engine Torque Limit	4670**	15,376	USN, USAF
2,153 ft-lb	5920	15,376	OEI

Exhaust Nozzle Area 317 in.^{2}

**SHP

ELECTRONICS

VHF/UHF Radio AN/ARC 182	Radar Beacon APX 78	Inertial Nav System SKN 2443 (CFE)
VHF/UHF Encryption KY 58	Radar Warning APR 39A	Mission Computers AYK-14 (XN-8)
VHF/UHF Control Head C 10319A	Missile Warning AAR 47	Interface Units (CFE)
HF Radio ARC 190 ARC 190	Chaff Flare/ Jammer Dispenser ALE 39	VSLED (CFE)
HF Encryption ANDVT	SAHRS USN-2	DTS (CFE)
IFF APX 100	Tacan ARN 118	MFD (CFE)
IFF Security Kit 1A TSEC	VOR/ILS MB ARN 144	DEU (CFE)
Intercom AIC 30 (CFE)	Doppler APN 217	CDU (CFE)
FM Homing (CFE)	Core APN 232	HMD (CFE)
Digital Message Device OA 8990	VHF/UHF ADF OA 8697	FLIR (CFE)
		Multifunction Radar (CFE)
		Night Vision Goggles (CFE AN/AVS-6)

MISSION AND DESCRIPTION

The V-22 is a multimission aircraft designed for use by all services. The unique ability of the tiltrotor to combine VTOL operations with high altitude and high airspeed flight permits such multimission applications.

The U.S. Marine Corps will use the V-22 for Vertical Assault Transport of troops, equipment and supplies from amphibious assault ships and land bases.

The U.S. Navy will use the V-22 for combat search and rescue, delivery and retrieval of special warfare teams, and logistics transportation in support of the fleet.

The U.S. Air Force will use the V-22 for long range special operations missions, delivering and retrieving U.S. Army special forces troops and equipment at mission radii in excess of 500 NM.

The U.S. Army will use the V-22 for aero medical evacuation, special forces infiltration and exfiltration and long range assault logistics support.

The V-22 Osprey is a tiltrotor aircraft with two 38 foot rotor systems and engine/transmission nacelles that are mounted on each wing tip. These rotor systems are powered by two T406-AD-400 engines. The aircraft operates as a helicopter when taking off and landing vertically. Once airborne the nacelles are rotated 90 degrees forward thus converting the aircraft into a turboprop airplane for high speed, fuel-efficient flight. The rotors are synchronized by means of an interconnect transmission shaft that runs through the wing between the two nacelle mounted transmissions. This shaft also provides power transmission from one rotor system to the other in case of an engine failure.

The aircraft folds up compactly for stowage aboard ship. This is accomplished by folding the rotor blades inboard in front of the wing then swiveling the wing to be parallel to the fuselage.

The V-22 airframe is almost completely composite construction. It has crashworthy seating for combat troops, two external cargo hooks for carriage of outsized equipment, a rescue hoist, a cargo winch and pulley system of loading and unloading heavy internal cargo loads and an aft loading ramp which permits quick egress and exit of both troops and cargo.

The Osprey is capable of all weather instrument flight, day or night, and continuous operation in moderate icing conditions. The Navy and Air Force aircraft are equipped to fly in these same conditions at very low level.

Although all services use a common aircraft, the Marine Corps and Army designation is MV-22A, the Air Force designation is CV-22A and the Navy designation is HV-22A.

DEVELOPMENT

First Flight (estimated)	1988
Service Use (estimated)	1991

DIMENSIONS

Main Rotor

Diameter:	38 ft
Disk Area:	2,268 ft^2
Blade Area:	281.52 ft^2
No. of Blades:	3 per rotor

Length		Height		Width	
Maximum	689 inches	Maximum	261 inches	Maximum	1,014.9 inches
Folded	751 inches	Folded	217 inches	Folded	221 inches
				Tread	182.8 inches

WEIGHTS

Revision A

Loading	(USMC) Weight (lb)	Load Factor Airplane	Load Factor Helicopter
Empty	31,818		
Operating	32,623		
Design	39,500	+4.0, −1.0	+3.0, −.5
Combat	42,712	+3.7, −.92	+2.77, −.46
Max Takeoff (VTO)	47,500	+3.3, −.84	+2.6, −.42
Max Takeoff (STO)	55,000	+2.87, −.72	
Self Deployment (STO)	60,500	+2.61, −.65	

FUEL AND OIL

FUEL

Gal.	No. & Type of Tanks	Location
2,430	2 Non Self-Sealing	Cabin (Self Deployment)
928	2 Partial Self-Sealing	Sponsons
199	2 Self-Sealing	Wing
588	8 Self-Sealing	Wing
300	1 Partial Self-Sealing	Aft Sponson

Fuel Grade JP-4/JP-5/JP-8

Fuel Spec MIL-T-5624

OIL

Engine (gal)	1.93	Spec: DOD-L-85734
Transmission (gal)	25.375	Spec: DOD-L-85734

ORDNANCE

Provisions for Two (2) .50 Caliber
Cabin Guns.
Additional Provision for Ramp
Mounted Gun (USAF only)

ACCOMMODATIONS

Crew (mission)	3
Cabin Size Clearance	
Length:	290 inches
Width:	71 inches
Height:	72 inches
Usable Volume:	858 ft^3
Rescue Hatch Dimensions:	40 inches x 29 inches
Provision for Troop Seats:	24
Provision for Litters:	12
Rescue Hoist Capacity:	600 lb
Cargo Hook Capacity:	15,000 lb
Cargo Floor Limit:	300 psf
Max Cargo Weight:	20,000 lb

PERFORMANCE SUMMARY (STANDARD DAY CONDITIONS)

Revision A

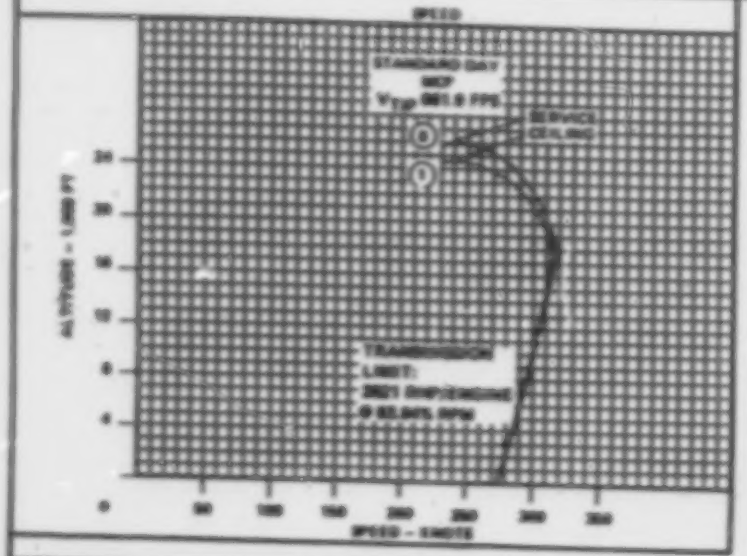
TAKE-OFF LOADING CONDITION		Amphibious Assault (Troops) ①	Amphibious Assault (Cargo) ②	Land Assault (Troops) ③	Land Assault (Cargo) ④	Combat Search and Rescue ⑤	Special Operations (A) ⑥	USMC Self Deployment ⑦
TAKE-OFF WEIGHT (E)	lb.	40,021	44,750	44,787	44,081	47,821	53,594	60,500
*Fuel internal/external (JP-5) (6.8 lb/gal)	lb./lb.	6,830	3,530	6,584	3,330	13,388	15,387 (A)	28,110
Payload	lb.	5,700	8,300	5,700	8,300	600	2,000	0
Disc loading	lb./sq. ft.	18.8	19.5	19.7	19.4	21.1	23.6	26.7
Vertical rate of climb at SL /Std	fpm.	1,080 (F)	1,340 (F)	(F)	1,410 (F)	1,000 (G)	NA	NA
Absolute hovering ceiling (OGE Std)	ft.	5,000 (F)	6,500 (F)	5,500 (F)	6,800 (F)	4,400 (B)	NA	NA
✓Max. rate of climb at SL/Std (H)	fpm.	2,320	2,400	2,350	2,420	2,030	1,490	1,080
Service ceiling (G)	ft.	24,560	24,930	24,680	25,020	23,110	20,180	17,950
Speed at S.L. (H)	kn.	273	274	274	274	272	266	264
Max. speed/altitude (Std Day) (H)	kn./ft.	316/18,000	315/18,000	316/18,000	316/18,000	314/17,000	305/16,040	294/16,000
O.E.I. Service ceiling (G)	ft.	11,200	11,600	11,400	11,600	8,200	5,700	S.L. (B)
Min. speed (O.E.I.) (B) (C)	kn.	38	37	38	37	45	63	90
Max. speed (O.E.I.) (B) (C)	kn.	231	232	231	233	228	221	202
Combat radius	n. mi.	2 x 50	50	200	50	460	520	NA
Mission time	hrs.	1.94	0.675	2.01	0.710	4.0	4.8	NA
Average cruising speed	kn.	274	170	245	170	244	251	NA
Cruising altitude	ft.	3,000	3,000	3,000	3,000	2,000	1,000	NA
Range/Mission Time nmi/hours		515/2.21	108/.83	495/2.20	101/.78	1,030/4.24	1,110/4.47	2,100/7.82
Average cruising speed	kn.	233	130	225	130	241	240	264
Cruising altitude	ft.	3,000	3,000	3,000	3,000	2,000	1,000	12,000 25,000
Maximum endurance	hrs.	2.60	.83	2.50	.78	5.20	5.00	10.01
Endurance speed	kn.	175	130	174	130	171	170	223/170
Endurance altitude	ft.	3,000	3,000	3,000	3,000	2,000	1,000	10,000
Combat Loading Condition ⑧		60% fuel		60% fuel		60% fuel	60% fuel	
Combat Weight	lb.	42,486		42,333		43,773	47,609	
Engine Power		MCP		MCP		MCP	MCP	
Fuel	lb.	4,103		3,950		8,021	9,220	
Combat Speed/Cruise Altitude (D) (H)	kn./ft.	294/3,000		294/3,000		280/2,000	275/1,000	
Rate of Climb/Cruise Altitude (D) (H)	fpm./ft.	2,670/3,000		2,590/3,000		2,580/2,000	2,020/1,000	
Combat Ceiling (500 fpm) (G)	ft.	22,200		22,400		23,700	20,800	
Rate of Climb at SL/STD (H)	fpm.	2,880		2,620		2,600	2,830	
Max. speed at SL/Std (H)	kn.	276		276		276	272	
Max speed/altitude time airspeed (H)	kn./ft.	310/18,000		310/18,000		316/18,000	314/17,000	
Landing Weight		33,616		33,586		38,000	39,928	37,183
Fuel	lb.	862		861		1,337	1,637	2,012
Absolute hovering ceiling (OGE)	ft.	14,200 (F)		14,240 (F)		12,800 (B)	10,290 (B)	11,800 (F)

NOTES

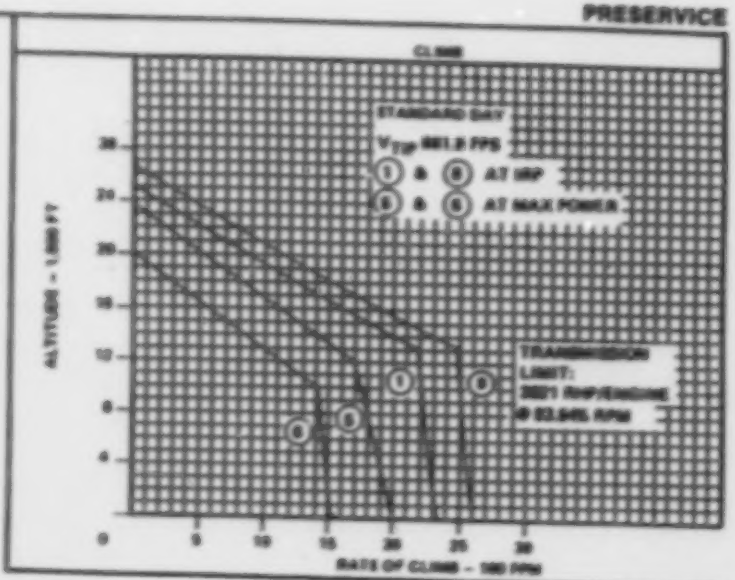
PERFORMANCE BASIS: ESTIMATED DATA GUARANTEE LEVELS OF PERFORMANCE (SD 572 1) AND ENGINE SPECIFICATION FUEL FLOWS
*WING AUXILIARY FUEL TANKS ARE USMC MISSION ROLE EQUIPMENT

(A) JP-4 FUEL (6.5 LB/GAL)
(B) MAX POWER
(C) SEA LEVEL
(D) MISSION CRUISE ALTITUDE
(E) ADD 200 LB OF TAXI/WARM UP FUEL TO OBTAIN RAMP WT
(F) IRP
(G) MCP
(H) XMSN LIMIT: 3521 RHP/ENG @ CRUISE RPM (V_{TIP} = 661.8 FPS)

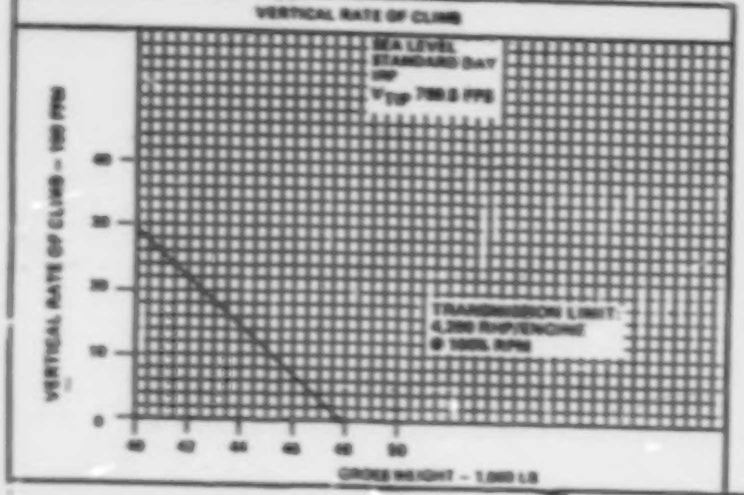
SPEED



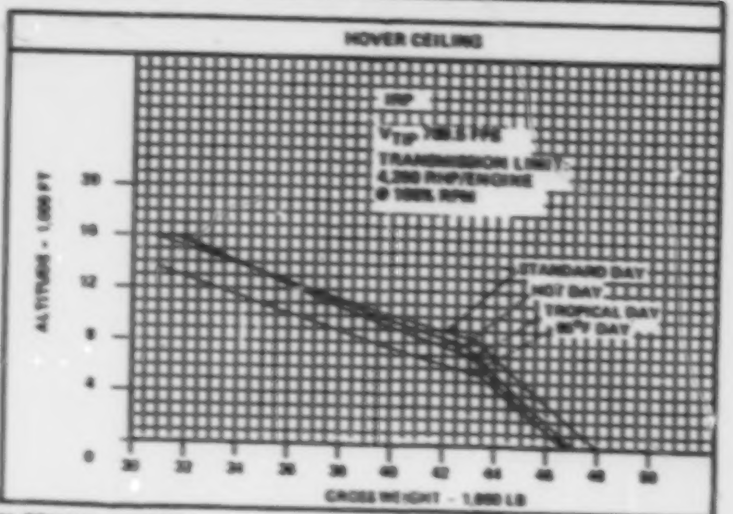
CLIMB



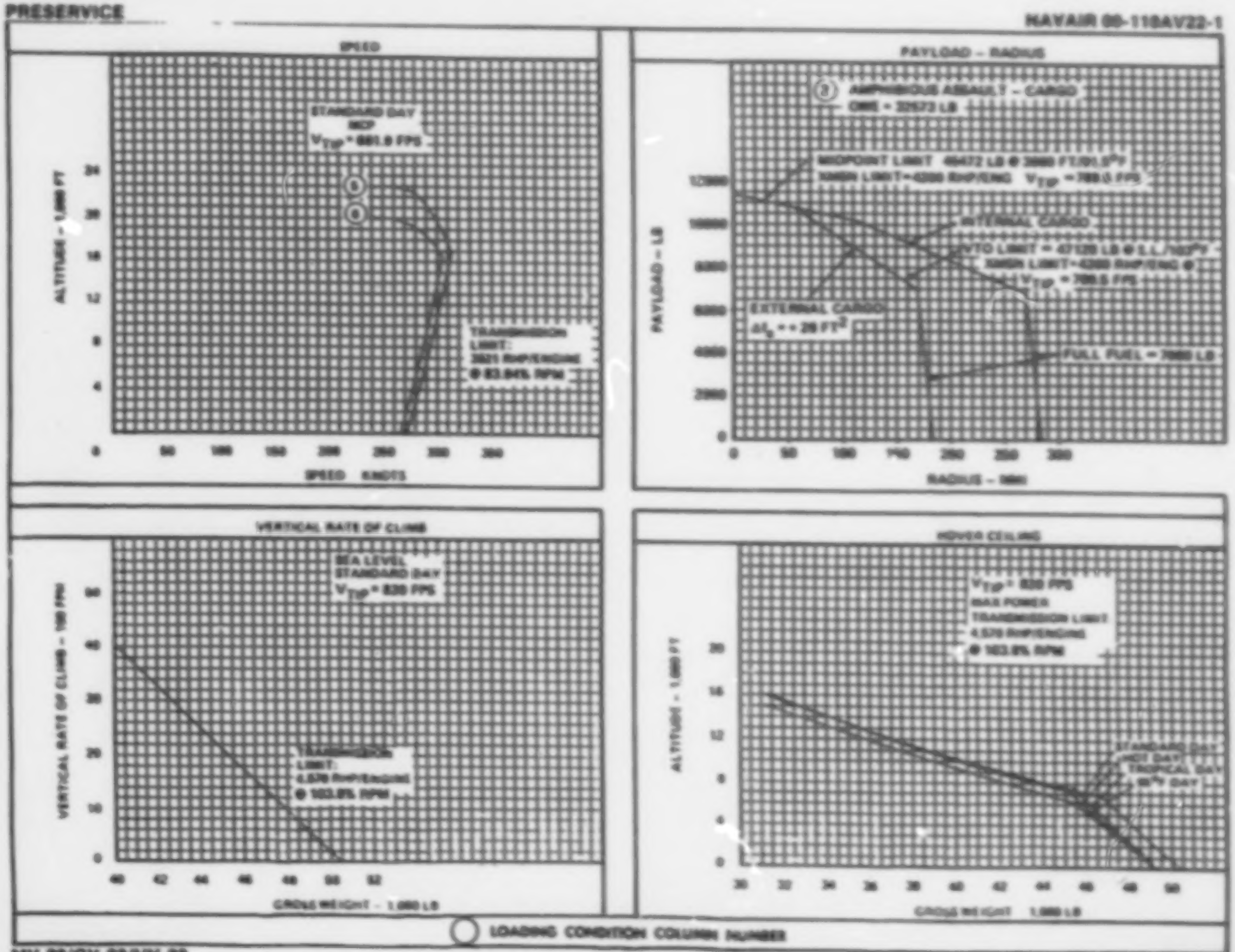
VERTICAL RATE OF CLIMB



HOVER CEILING

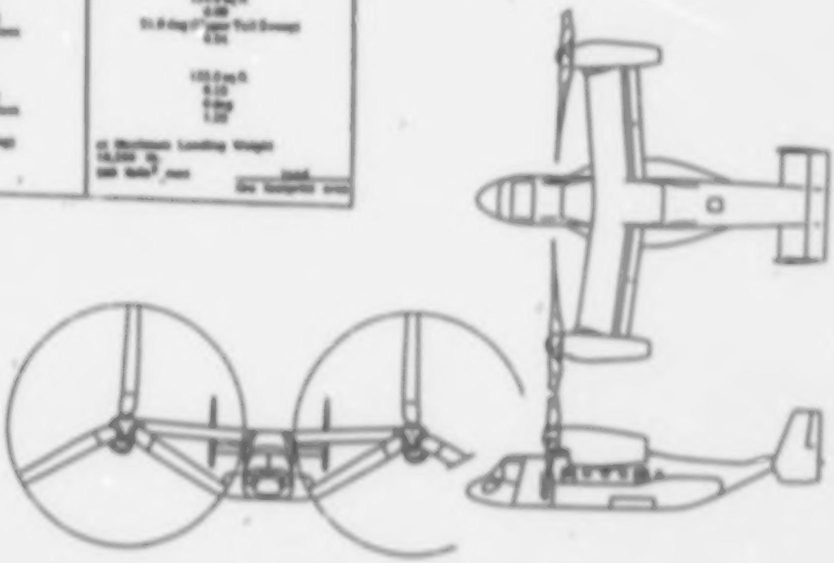


○ LOADING CONDITION COLUMN NUMBER


SPEED
STANDARD DAY
MCP
V_{TIP} = 881.8 FPS
①
②
TRANSMISSION
LIMIT:
3821 RHP/ENGINE
@ 83.84% RPM
ALTITUDE – 1,000 FT
0
4
8
12
16
20
24
0
50
100
150
200
250
300
350
SPEED KNOTS
PAYLOAD – RADIUS
③ AMPHIBIOUS ASSAULT – CARGO
OWE = 32573 LB
MIDPOINT LIMIT 46472 LB @ 3000 FT/91.5°F
XMSN LIMIT=4300 RHP/ENG V_{TIP} = 789.5 FPS
INTERNAL CARGO
VTO LIMIT = 47120 LB @ S.L./103°F
XMSN LIMIT=4300 RHP/ENG @
V_{TIP} = 789.5 FPS
EXTERNAL CARGO
Δf_e = +20 FT^2
FULL FUEL = 7980 LB
PAYLOAD – LB
0
2000
4000
6000
8000
10000
12000
0
50
100
150
200
250
300
RADIUS – NM
VERTICAL RATE OF CLIMB
SEA LEVEL
STANDARD DAY
V_{TIP} = 830 FPS
TRANSMISSION
LIMIT:
4,570 RHP/ENGINE
@ 103.8% RPM
VERTICAL RATE OF CLIMB – 100 FPM
0
10
20
30
40
50
40
42
44
46
48
50
52
GROSS WEIGHT – 1,000 LB
HOVER CEILING
V_{TIP} = 830 FPS
MAX POWER
TRANSMISSION LIMIT
4,570 RHP/ENGINE
@ 103.8% RPM
STANDARD DAY
HOT DAY
TROPICAL DAY
90°F DAY
ALTITUDE – 1,000 FT
0
4
8
12
16
20
30
32
34
36
38
40
42
44
46
48
50
GROSS WEIGHT 1,000 LB
LOADING CONDITION COLUMN NUMBER

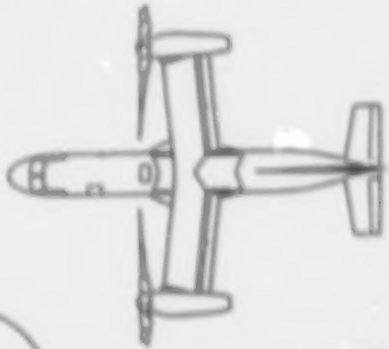
BELL-BOEING CTR-22A/B

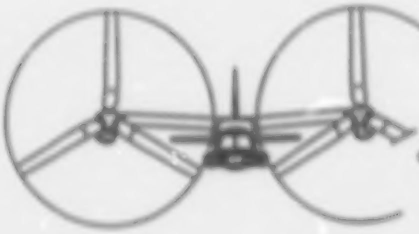
ITEM	DATA
Overall	
Length	[illegible]
Width w/Rotor	[illegible]
Height	[illegible]
Wing	
Span	[illegible]
Area	[illegible]
Sweep at 25% Chord	[illegible]
Thickness Ratio	[illegible]
Aspect Ratio	[illegible]
MAC	[illegible]
Taper Ratio	[illegible]
Propulsion	
Rotor Diameter	[illegible]
Conversion Type	Tilting Nacelle
Type (No. Blades, Gimbaled)	[illegible]
Engine Type (No.)	[illegible]
T.O. (5 min) Rating	[illegible]
30 sec rating	[illegible]
Transmission Rating, hp	
Hover OEI	[illegible] (CTR-22A) [illegible] (CTR-22B)
Hover AEO	[illegible]
Fuselage	
Length	[illegible]
Width	[illegible]
Height	[illegible]
Cabin Height (min/max)	[illegible]
Cabin Length	[illegible]
Cabin Width (max)	[illegible]
Landing Gear	
Main Gear Tire Size	[illegible] Nose [illegible] Main
Main Gear Type	Twin Wheel Retracting
Main Gear Track	[illegible] in.
Wheel Base (F.G. - M.G.)	[illegible] in.
Tail Configuration	H-Tail
Vertical Stabilizer	
Area	[illegible]
Thickness Ratio	[illegible]
Sweep at 25% Chord	[illegible] Tail Sweep)
Tail Volume Coefficient	[illegible]
Horizontal Stabilizer	
Area	[illegible]
Thickness Ratio	[illegible]
Sweep at 25% Chord	[illegible]
Tail Volume Coefficient	[illegible]
Wheel & Tire Loading (For Use in Pavement Sizing) Single Post Load Single Tire Load	at Maximum Landing Weight [illegible] lb [illegible]

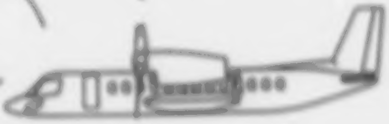


BELL-BOEING CTR-22C

ITEM	DATA
Overall	
Length	[illegible]
Width, with Rotors	[illegible]
Height	[illegible]
Wing	
Span	[illegible]
Area	[illegible]
Sweep at 25% Chord	[illegible]
Thickness Ratio	[illegible]
Aspect Ratio	[illegible]
MAC	[illegible]
Taper Ratio	1.0
Propulsion	
Rotor Diameter	[illegible]
Conversion Type	Tilting Nacelle
Type (No. Blades, Gimbaled)	3
Engine Type (No.)	T406-AD-400 (2)
T.O. (5 min) Rating	[illegible]
30 sec Rating	[illegible]
Transmission Rating, hp	
Hover OEI	[illegible]
Hover AEO	[illegible]
Fuselage	
Length	[illegible]
Width	[illegible]
Height	[illegible]
Cabin Height (nominal)	[illegible]
Cabin Length	[illegible]
Cabin Width (max)	[illegible]
Landing Gear	
Main Gear Tire Size	[illegible] in. dia. Nose [illegible] in. dia. Main
Main Gear Type	Twin Wheel Retracting
Main Gear Track	[illegible] in.
Wheel Base (F.G. - M.G.)	[illegible] in.
Tail Configuration	Conventional
Vertical Stabilizer	
Area	[illegible]
Thickness Ratio	[illegible]
Sweep at 25% Chord	[illegible]
Tail Volume Coefficient	[illegible]
Horizontal Stabilizer	
Area	[illegible]
Thickness Ratio	[illegible]
Sweep at 25% Chord	[illegible]
Tail Volume Coefficient	[illegible]
Wheel & Tire Loading (For Use in Pavement Rating) Single Post Load Single Tire Load	at Maximum Landing Weight [illegible] lb [illegible] max [illegible]

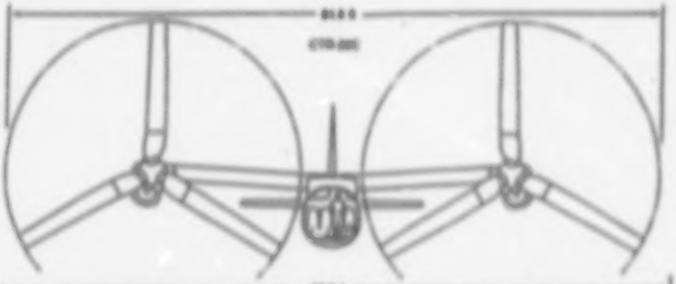


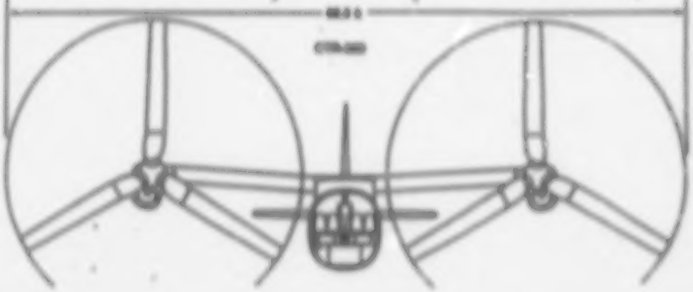




BELL-BOEING CTR-22D

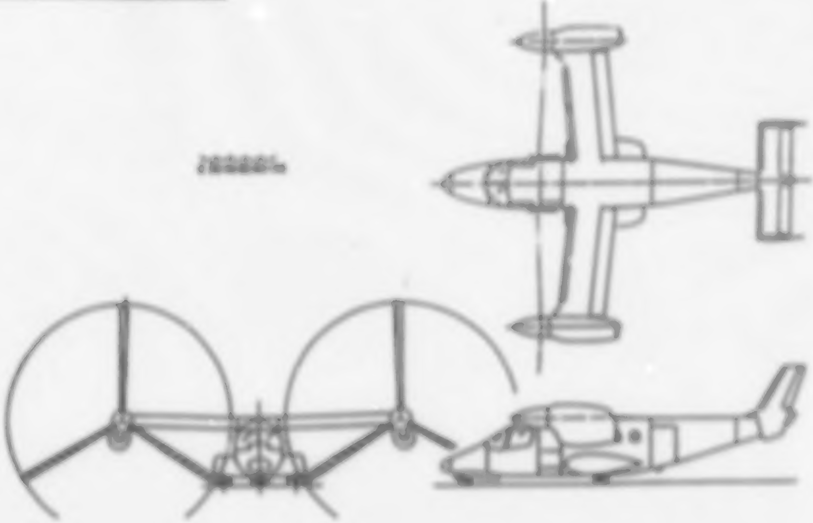
ITEM	DATA
Overall	
Length	[illegible] ft
Width W/Rotors	[illegible] ft
Height	[illegible] ft
Wing	
Span	[illegible] ft
Area	[illegible] ft²
Sweep at 25% Chord	[illegible] deg
Thickness Ratio	[illegible]
Aspect Ratio	[illegible]
MAC	[illegible] ft
Taper Ratio	1.0
Propulsion	
Rotor Diameter	[illegible] ft
Conversion Type	Tilting Nacelle
Type (No. Blades, Gimbaled)	3
Engine Type (No.)	Allison [illegible] (2)
T.O. (5 min) Rating	[illegible] shp
30 sec rating	[illegible] shp
Transmission Rating, hp	
Hover OEI	[illegible] shp
Hover AEO	[illegible]
Fuselage	
Length	[illegible] ft
Width	[illegible] ft
Height	[illegible] ft
Cabin Height (interior)	[illegible] ft
Cabin Length	[illegible] ft
Cabin Width (max)	[illegible] ft
Landing Gear	
Main Gear Tire Size	TBD Nose TBD Main
Main Gear Type	Twin Wheel Retracting
Main Gear Track	TBD
Wheel Base (M.G. - N.G.)	TBD
Tail Configuration	Conventional
Vertical Stabilizer	
Area	[illegible] ft²
Thickness Ratio	[illegible]
Sweep at 25% Chord	[illegible] deg
Tail Volume Coefficient	[illegible]
Horizontal Stabilizer	
Area	[illegible] ft²
Thickness Ratio	[illegible]
Sweep at 25% Chord	[illegible] deg
Tail Volume Coefficient	[illegible]





BELL-BOEING CTR-800

CTR - 800	
Overall	
Length	[illegible] ft
Width w/Rotors	[illegible] ft
Height	[illegible] ft
Wing	
Span	[illegible] ft
Area	[illegible] SF
Sweep at 25% Chord	[illegible] deg
Thickness Ratio	[illegible]
Aspect Ratio	[illegible]
M.A.C.	[illegible] ft
Taper Ratio	1.0
Fuselage	
Length	[illegible] ft
Width	[illegible] ft
Height	[illegible] ft
Cabin Height	[illegible] ft
Cabin Length	[illegible] ft
Cabin Width (Max.)	[illegible] ft
Landing Gear	
Main Gear Tire Size	[illegible] [illegible]
Main Gear Type	Twin Wheel, Retracting
Main Gear Track	[illegible] in.
Wheel base (F.G. - M.G.)	[illegible] in.
Tail Configuration	[illegible]
Vertical Stabilizer	
Area	[illegible] SF
Thickness Ratio	[illegible]
Sweep at 25% Chord	[illegible] deg (Upper Tail Swept)
Tail Volume Coefficient	[illegible]
Horizontal Stabilizer	
Area	[illegible] SF
Thickness Ratio	[illegible]
Sweep at 25% Chord	0 deg
Tail Volume Coefficient	[illegible]
Rotor System	
Rotor Diameter	[illegible] ft
Conversion Type	Tilting Nacelle
Type (i.e. Rigid, Gimbaled)	[illegible]
Drag Area (With Value of Drag)	[illegible] SF

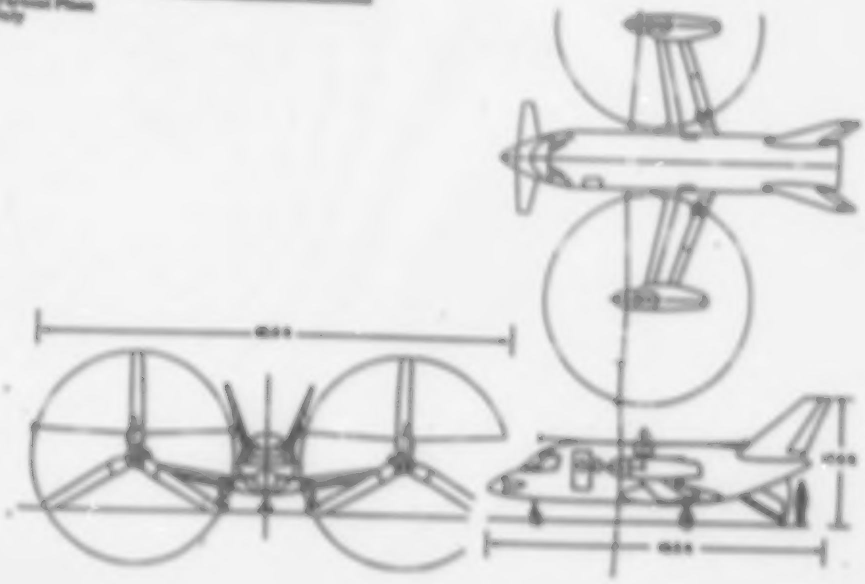


BELL-BOEING CTR-1900

	CTR-1900
Overall	
Length	48.0 ft.
Width	80.0 ft.
Height	17.0 ft.
Wing	
Span	37.0 ft.
Area	200.0 ft.
Sweep at 25% Chord	-15.0 deg
Thickness Ratio	.24
Aspect Ratio	[illegible]
MAC	[illegible]
Taper Ratio	0.80
Fuselage	
Length	40.00 ft.
Width	7.07 ft.
Height	7.07 ft.
Cabin Height	[illegible]
Cabin Length	[illegible]
Cabin Width (Max)	7.00 ft.
Landing Gear	
Main Gear Tire size	[illegible]
Main Gear Type	[illegible]
Main Gear Track	Twin Wheel, Retracting 130.0 in.
Wheel Base (N.G. - M.G.)	204.0 in.
Tail Configuration	V
Vertical Stabilizer	
Area	*50.0 ft²
Thickness Ratio	0.10
Sweep at 25% Chord	40 deg
Tail Volume Coefficient	*0.05
Horizontal Stabilizer	
Area	[illegible]
Thickness Ratio	*0.10
Sweep at 25% Chord	[illegible]
Tail Volume Coefficient	[illegible]
Rotor System	
Rotor Diameter	38.0 ft.
Conversion Type	Tilting Pylon
Type (No. Blades, Gimbaled)	3
Drag Area (w/o Induced Drag)	[illegible]

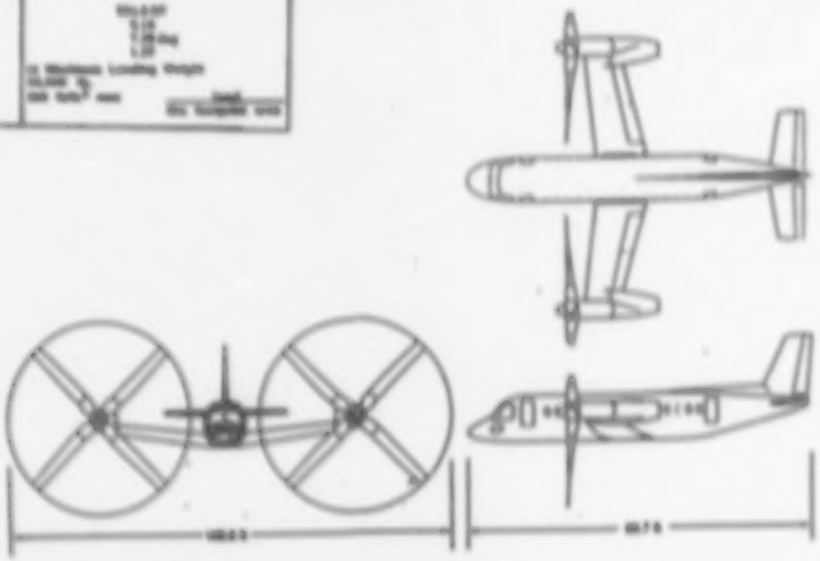
* Based on Projected Area in Vertical Plane

* Based on Canard Surfaces Only



BELL-BOEING CTR-7500

ITEM	DATA
Overall	
Length	[illegible]
Width w/Rotors	[illegible]
Height	[illegible]
Wing	
Span	[illegible]
Area	[illegible]
Sweep at 25% Chord	[illegible]
Thickness Ratio	[illegible]
Aspect Ratio	[illegible]
MAC	[illegible]
Taper Ratio	[illegible]
Propulsion	
Rotor Diameter	[illegible]
Conversion Type	Tilting Nacelle
[illegible]	[illegible]
Engine Type (No.)	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
Transmission Rating, hp	
[illegible]	[illegible]
[illegible]	[illegible]
Fuselage	
Length	[illegible]
Width	[illegible]
Height	[illegible]
Cabin Height	[illegible]
Cabin Length	[illegible]
Cabin Width	[illegible]
Landing Gear	
Main Gear Tire Size	[illegible]
Main Gear Type	Twin Wheel, Retracting
Main Gear Track	[illegible]
Wheel Base	[illegible]
Tail Configuration	Conventional
Vertical Stabilizer	
Area	[illegible]
Thickness Ratio	[illegible]
Sweep at 25% Chord	[illegible]
Tail Volume Coefficient	[illegible]
Horizontal Stabilizer	
Area	[illegible]
Thickness Ratio	[illegible]
Sweep at 25% Chord	[illegible]
Tail Volume Coefficient	[illegible]
Wheel & Tire Loading (For Use in Pavement Rating) Single Wheel Load Single Tire Load	@ Maximum Landing Weight [illegible]



EUROFAR Baseline Configuration

Dimensions

Length	19.40 m
Width	2.48 m
Span	14.70 m

Rotor Diameter - 11.21 m
Radius - 5.605 m

Capacity/Power

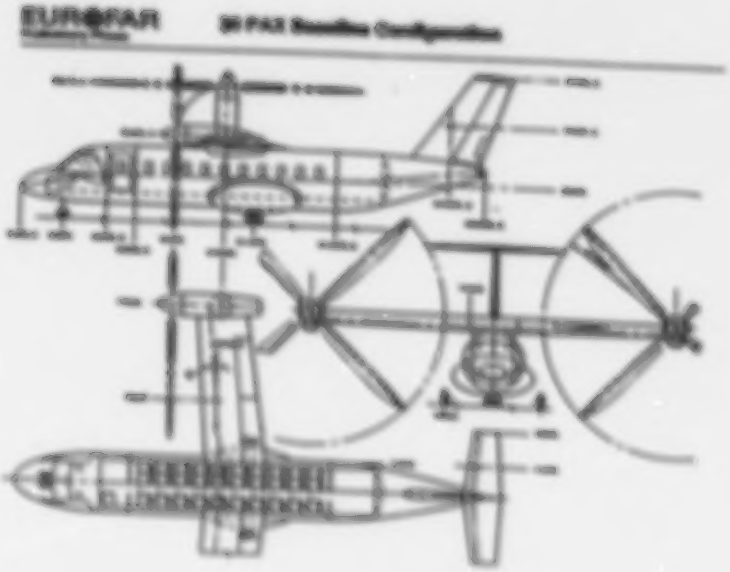
Passengers	30/33 (3 abreast)
Max TOGW	15 000 kg
Design GW	13 650 kg

Engines 2 x PW 300 TS

Performance

- All weather flight capability
- Use of advanced air traffic control

HOGE	3000 m
Climb in helicopter mode	11 m/s
Climb in aircraft mode	10 m/s
Vertical Climb in helicopter mode	7.2 m/s
OEI Climb in helicopter mode	8.0 m/s
Cruise Altitude	7500 m
Maximum cruise speed	335 kts
best range speed	295 kts
Range (with IFR reserve)	
normal	1230 km
maximum	2500 km
specific	0.93 km/kg-fuel


EUROFAR
30 PAX Baseline Configuration

ISHIDA TW-68

Passenger Capacity

Corporate Configuration	9
Commuter Configuration	14
Max Passengers	16

Dimension

Wing Span	36 Ft.	(10.97 m)
Wing Chord	7.08 Ft.	(2.16 m)
Length	39.38 Ft.	(12 m)
Height	13.40 Ft.	(4.08 m)
Interior Width	64"	(1.62 m)
Cabin Length	15.83 Ft.	(4.82 m)
Cabin Height	63"	(1.6 m)

Weights

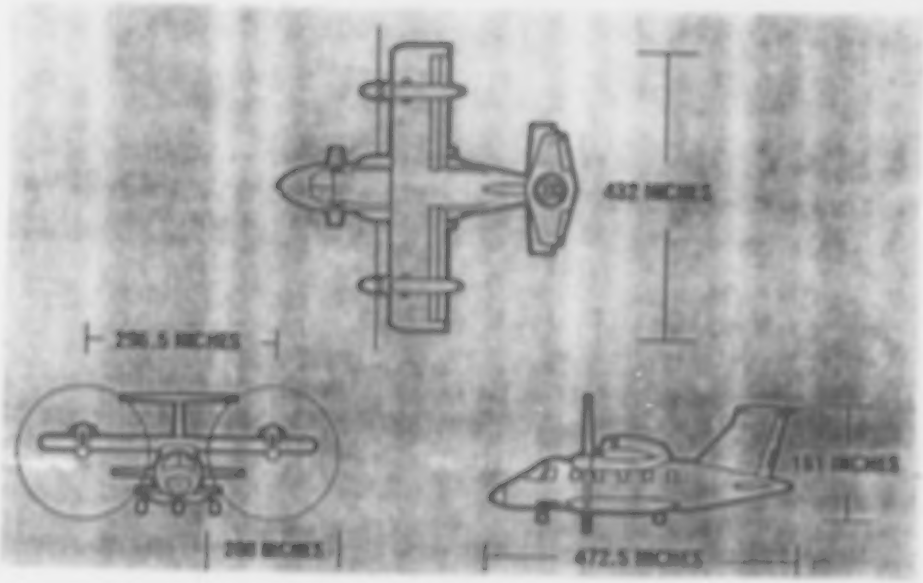
Max T.O. STOL	16,500 Lbs.	(7,483 kg)
Max T.O. VTOL	12,500 Lbs.	(5,669 kg)

Propulsion

Engine - Pratt & Whitney
Propeller - 5 Blades 200" in Dia.
Max RPM - 800

Performance

Max Speed	350 KTS	(646 kmh)
Max Cruise	268 KTS	(495 kmh)
Best Range	187 KTS	(345 kmh)
Best Endurance	170 KTS	(314 kmh)


432 INCHES
236.5 INCHES
288 INCHES
151 INCHES
472.5 INCHES

MAGNUM T/R MTR-201

First 200 units should be a minimum change to XV-15 and Mitsubishi MU-2

Target markets:

corporate, EMS, resources-related/utility
(not for airline operations)

Applied for normal (not transport) category

Engines: 1750 to 2200 hp

Passenger Capacity: 9 passengers

Features:

pressurized cabin
two pilots
high-wing

Performance:

Speed	350 mph
Altitude	30 000 ft or higher
Range	1600 km, 1000 miles

APPENDIX 3
TRADE-OFFS BETWEEN AIRSPACE CONSTRAINTS AND CTR PERFORMANCE

INTRODUCTION

Context

Discussions among planners concerning the siting of vertiports in relation to the vehicle flight performance capability as measured by the possible approach and departure flight profiles of CTR aircraft.

Objective

General assessment of the impacts related to different levels of CTR aircraft performance in terms of possible approach and departure flight profiles.

OPTIONS

Different levels of CTR performance, as defined in terms of the following basic options for approach and departure flight profiles:

1) STOL approach
2) 6 degree approach
3) 16 degree approach
4) 25 degree approach
5) 90 degree approach (vertical)

IMPACTS

Implications of the above levels of CTR performance on the following parameters:

a) vertiport airfield area requirements
b) land requirements for protected airspace around vertiports
c) market capture, in relation to siting options as a function of space requirements
d) power requirement for 100% payload utilization
e) operational costs

f) navigation equipment requirements
g) vehicle control system
h) area of noise impact

COMPARATIVE MATRIX

The following page presents a comparative matrix in which the selected levels of CTR vehicle performance, in terms of achievable approach and take-off procedures, are related to the specific parameters identified above. The subsequent paragraphs describe these relationsships in greater detail.

Parameters	Vertical Angle of Approach / Departure				
	STOL	6°	16°	25°	90°
a) airfield area	max	base	base	base	base
b) protected airspace	max	>16°	>25°	>90°	min
c) market capture	min			——	max
d) power req'ts	min	base	base	base	max
e) operational cost	min	base	base	base	max
f) navaids	MLS	Std. MLS	Std. MLS	Std. MLS	Improved Vertical Guidance
g) vehicle control systems	Existing technology	Existing technology	Existing technology	New technology	New technology
h) noise impact area	max	>16°	>25°	>90°	min

Airfield Area

For the purposes of the present exercise, the airfield area required consists of the essential vertiport airside components: the TLOF and FATO (Touchdown/Lift-Off and Final Approach/Take-Off) areas. It does not include the apron, taxiways, passenger terminal and other elements of a typical vertiport which are independent of the flight performance capability of the aircraft.

For all the VTOL options, regardless of approach angle capability, the TLOF/FATO requirement is identical and equivalent to a square area approximately 76 m x 76 m. For STOL operations, the requirement would increase to a rectangle approximately 274 m x 76 m, as illustrated in Figure 17 in Section 3.2.

Protected Airspace

The protected airspace requirement refers to the areas which must be kept free of obstacles and zoned accordingly to control present and future development accordingly. It is directly related to the geometrics of the approach/take-off angles achievable by the aircraft. The following figure provides a graphic illustration in parametric terms of the relationship between different angles and the ground area affected, which decreases as the vertical approach/departure angle increases.

Market Capture

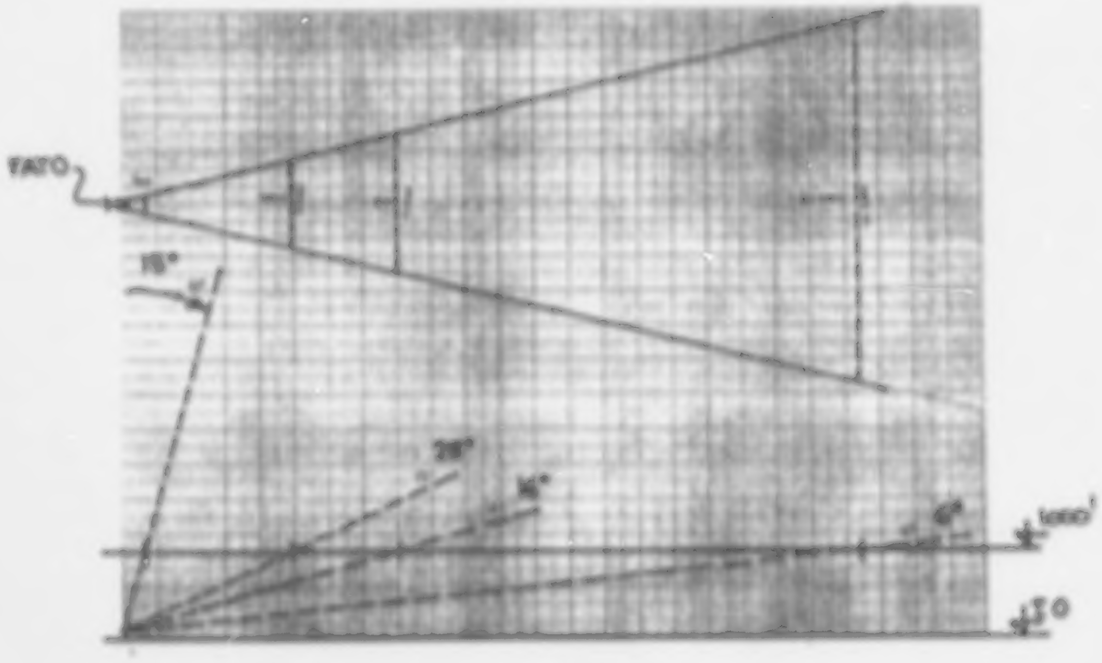
Market capture refers to the fact that vehicles with minimal ground area requirements (airfield and protected airspace) will have the flexibility to serve vertiport sites closer to the centers of demand, thus maximizing potential market capture, as indicated in the table.

Power Requirement

The vehicle power requirement refers to the maximum engine power required to meet OEI certification criteria under different approach/take-off angles. In general terms, the greater the horizontal motion vector the lower the power requirement. This parameter constitutes the base criteria for engine design and has a direct relationship to capital and operating costs.

AREA SUBJECT TO HEIGHT RESTRICTION

Vehicle Performance	Area* hectares	Index
vertical	64	1
25°	749	12
16°	1 927	30
6°	12 849	200
STOL	12 849	200


FATO
15°
25°
16°
6°
1000'
±0

* for two-directional operation

Operational Cost

The operational costs relative to the different levels of CTR performance reflect the fuel consumption and maintenance requirements of the vehicles. These factors are closely related to the preceding factor, engine power requirement. Vertical take-off represents the most demanding and costly procedure and STOL operation the least.

Navigation Equipment

The navigation aids required for different CTR vehicle approach angles reflect the required vertical signal coverage for each angle. As discussed in Chapter 2.2, it is assumed that CTR operations will use MLS as the primary landing aid. For approach angles up to 30°, current MLS technology should provide adequate coverage, according to ICAO, possibly with some enhancement required at the upper range. Extension of MLS coverage beyond this vertical angle would involve additional computation and programming requirements. The practicality of such extensions would therefore have to be measured against the cost of other more specialized, and therefore potentially more economical, add-on methods of providing broader azimuth and vertical coverage.

Vehicle Control System

The systems required to permit the pilot to positively control the vehicle under different approach angles relate to factors such as inherent stability at low forward speed, pilot visibility, etc. Tests in progress on the V-22 indicate that existing CTR control technology will provide adequate capability up to and including 16° approaches. Beyond this point improved systems may be required.

Area of Noise Impact

The ground area impacted by CTR aircraft noise is related to vehicle performance levels in the sense that steeper angles will minimize the area subject to the noise generated in the helicopter mode.

APPENDIX 4
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APPENDIX 5
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APPENDIX 6
VERTIPORT PLANNING STUDIES

1. **Port Authority of New York & New Jersey**
Feasibility of tiltrotor use at the three airports of the New York City area.

Objectives: To evaluate the feasibility of tiltrotor operations at John F. Kennedy, Laguardia and Newark airports to increase their capacity.
Length of programme: From January 1989 to February 1990.
Resources involved: A budget of $250,000 was allocated from the FAA; study carried out by the Rand Corporation.

Site study for tiltrotor vertiport in Manhattan.

Objectives: To evaluate the feasibility of sites in Manhattan (NYC) for eventual tiltrotor operations.
Length of programme: From September 1989 to October 1990.
Resources involved: A budget of $350,000 was allocated from the FAA; study carried out by Flight Transportation Associates.

2. **Washington D.C.**
Vertiport/Heliport feasibility study.

Objectives: To assess the needs of the region's current heliport/helicopter system.
Length of programme: From December 1988 to Spring 1990.
Resources involved: A budget of $85,000 was allocated from the US DOT/FAA (90%) and from matching local funds (10%); study carried out by the Metropolitan Washington Council of Governments.

3. **California**
Civil tiltrotor aircraft feasibility study for the state of California.

Objectives: To determine the feasibility of civil tiltrotor passenger service in California; also, to look at other uses such as search-and-rescue, aero-medical, etc.
Length of programme: From September 1989 to December 1990.
Resources involved: A budget of $200,000 was allocated from the FAA; study carried out by the California Department of Transportation, Division of Aeronautics.

4. **Texas**
   Vertiport Design Study.

   Objectives: To study the feasibility of a regional vertiport system within a 300 nm radius of the Dallas-Fort Worth Metroplex.
   Length of programme: From October 1989 to April 1992.
   Resources involved: A budget of $200,000 was allocated from federal funds and another of $20,000 from state funds; study carried out by the Texas Department of Aviation.

5. **Southern California**

   Objectives: To determine the feasibility of developing scheduled tiltrotor/ vertiport service within the Los Angeles Basin.
   Length of programme: From August 1989 to May 1990.
   Resources involved: A budget of $150,000 was allocated from the FAA, Western Pacific Region; study carried out by the Southern California Association of Governments (SCAG).

6. **Alaska**

   Objectives: To analyse the civil tiltrotor and vertiport concept to determine if it is technologically, economically and institutionally feasible as an aviation system alternative for Alaska in the future.
   Length of programme: From September 1989 to August 1991.
   Resources involved: A budget of $250,000 was allocated from the FAA; study carried out by the Alaska Department of Transportation and Public Facilities.

7. **Illinois**

   Objectives: To study the feasibility of developing tiltrotor service between downtown Chicago and potential markets within a 450-500 mile radius.
   Length of programme: 18 months duration; completion: end of 1990.
   Resources involved: A budget of $200,000 was allocated from the Illinois Department of Transportation and the FAA; study carried out by the Illinois Department of Transportation, Division of Aeronautics.

8. **St. Louis**

   Objectives: Site selection and feasibility analysis for a heliport/vertiport in the downtown area.
   Length of programme: From October 1989 to October 1990.
   Resources involved: A budget of $135,000 was allocated from the FAA; study carried out by the City of St. Louis, Department of Community Development.

9. **Puerto Rico / Caribbean Basin**

   Objectives: To develop an experimental civil tiltrotor small package express service in the Caribbean.
   Length of programme: From May 1989 to May 1990.

10. **San Francisco**

    Objectives: To study the feasibility of a heliport/ vertiport in San Francisco.
    Length of programme: From August 1989 to February 1991.
    Resources involved: A budget of $315,000 was allocated by the Port of San Francisco; study carried out by Hoyle, Tanner and Associates.

11. **Dade County (Florida)**

12. **Orlando**

13. **South Dakota**

14. **Boston**